PROCEEDINGS

Strategic Analyses of the National River Linking Project (NRLP) of India

Series 2

Proceedings of the Workshop on Analyses of Hydrological, Social and Ecological Issues of the NRLP

Upali A. Amarasinghe and Bharat R. Sharma, editors

IWMI
International
Water Management
Institute

CGIAR Challenge Program on
WATER & FOOD

Strategic Analyses of the National River Linking Project (NRLP) of India
Series 2

Proceedings of the Workshop on Analyses of Hydrological, Social and Ecological Issues of the NRLP

Upali A. Amarasinghe and Bharat R. Sharma, editors

INTERNATIONAL WATER MANAGEMENT INSTITUTE

IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Ghana, Pakistan, South Africa, Sri Lanka, and Thailand.

The editors: Upali A. Amarasinghe is Senior Researcher, International Water Management Institute (IWMI), New Delhi; Bharat R. Sharma is Senior Researcher and Head, International Water Management Institute (IWMI) New Delhi Office.

Amarasinghe, U.A.; Sharma, B.R., eds. 2008. *Strategic analyses of the National River Linking Project (NRLP) of India, series 2*. Proceedings of the Workshop on Analyses of Hydrological, Social and Ecological Issues of the NRLP. Colombo, Sri Lanka: International Water Management Institute. 500 p.

river basins / water supply / water demand / water transfer / dams / water storage / water balance / erosion / rain-fed farming / water harvesting / livestock / groundwater irrigation / surface irrigation / irrigation programs / crop yield / models / water market / tubewells / electricity / artificial recharge / social aspects / case studies / India

ISBN: 978-92-9090-694-0

Cover photo by the National Water Development Agency shows the ‘Proposed Links of the NRLP’.

(Peninsular component) 1. Mahanadi–Godavari; 2. Inchampalli–Nagarjunasagar; 3. Inchampalli–Pulichintala; 4. Polavaram–Vijayawada; 5. Almatti–Pennar; 6. Srisailam–Pennar; 7. Nagarjunasagar–Somasila; 8. Somasila–Grand Anicut; 9. Kattalai–Vaigai–Gundar; 10. Ken–Betwa; 11. Parbati–Kalisindh–Chambal; 12. Par–Tapi–Narmada; 13. Damanganga–Pinjal; 14. Bedti–Varda; 15. Netravati–Hemavati; 16. Pamba–Achankovil–Vaippar.

(Himalayan component) 1. Kosi–Mechi; 2. Kosi–Ghagra; 3. Gandak–Ganga; 4. Ghagra–Yamuna; 5. Sarda–Yamuna; 6. Yamuna–Rajasthan; 7. Rajasthan–Sabarmati; 8. Chunar–Sone Barrage; 9. Sone Dam–Southern Tributaries of Ganga; 10. Manas–Sankosh–Tista-Ganga; 11. Jogighopa–Tista–Farakka (Alternate); 12. Farakka–Sunderbans; 13. Ganga (Farakka)–Damodar–Subernarekha; 14. Subernarekha–Mahanadi.

Please direct inquires and comments to: *iwmi-reseach-news@cgiar.org*

Contents

Acknowledgement

The authors (hereinafter referred to as ‘We’) greatly appreciate the ‘Challenge Program for Water and Food’ of the Consultative Group of International Agriculture Research for providing financial support for the research project—‘Strategic Analyses and National River Linking Project of India’.

We also appreciate the guidance of the project advisory committee—the chairman Prof. M.S. Swaminathan, and others including Prof. Yojindra K. Alagh, Prof. Vijay S. Vyas, Prof. Kanchan Chopra, Prof. Vandana Shiva, Prof. Frank Rijsberman, Shri Anil D. Mohile, Shri S. Gopalakrishnan and Shri Deep Joshi. Their comments and suggestions at various stages of the project were immensely helpful to us.

We acknowledge the assistance of various government institutions, especially the Central Water Commission of the Ministry of Water Resources of India for providing the necessary data and published documents for the various research activities of this project. We thank Shri Suresh Prabhu, Shri A.D. Mohile, Dr. J. S. Samra, Prof. Y. K. Alagh, Dr. B. M. Jha, Dr. R. Sakthivadivel, Shri Ramaswamy Iyer, and Shri N. K.Bhandari for accepting our invitation to conduct the key-note presentations in the workshop. We also extend our thanks to the many national and IWMI researchers and NGOs for their support and collaboration in field data collection, research and preparation of draft research papers for this workshop.

We thank all the participants from various government institutions, universities, NGOs and INGOs, civil society and students for their useful deliberations at the workshop, and also all others who have worked behind the scenes to arrange the logistics and other requirements for holding a successful workshop. We also thank all the participants from various government institutions, universities, NGOs and INGOs, civil society and students for their useful deliberations at the workshop, and also all others who have worked behind the scenes to arrange the logistics and other requirements for holding a successful workshop.

Finally we express our thanks to Mr. Joseph Perera, Ms. Pavithra Amunugama and Mr. Nimal Attanayake for managing the editorial and production process of the proceedings.

Preface

In 2005, the International Water Management Institute (IWMI) and the Challenge Program on Water and Food (CPWF) started a 3-year research study on ‘Strategic Analyses of India’s River Linking Project’. The primary focus of the IWMI-CPWF project was to provide the public and policy planners with a balanced analysis of the benefits and costs of the different components of the National River Linking Project (NRLP). The first national workshop of the project was held at the NASC Complex, New Delhi from October 9-10, 2007. The major objective of this workshop was to share the results of various research activities conducted so far in the project, with the public, planners and policymakers.

Prof. M. S. Swaminathan, Chairman, M. S. Swaminathan Foundation, Chennai, India and also Chairman of the Advisory Committee of the IWMI-CPWF Research Project on NRLP, together with Shri Suresh Prabhu, Member of Parliament and former Minister of Water Resources, inaugurated the workshop. Dr. Madar Samad, Head, IWMI India Office, extended a warm welcome to the distinguished guests and invitees. He emphasized the importance of the project in the research program of IWMI in India and highlighted the contributions of the project to the present debate on the NRLP. Dr. Samad further explained that the national workshop was the culmination of a series of regional meetings held by IWMI. Dr. Peter G. McCornick, Director, IWMI Asia Program, in his keynote speech, emphasized the need to find timely solutions to the problems of rapidly changing environments of water demand and use in the world. He cited for example the emerging trends of scarcities as prompting possible substantial investments in water resource development and management in the future. He concluded it is, therefore, imperative that the research conducted under projects such as the NRLP need to keep pace with the changing ground realities in India and other countries across the world, and the best way to do this is to ensure quick dissemination of the wealth of research conducted by the NRLP teams.

This compendium of papers expects to serve this purpose. It presents the summaries of keynote speeches and presentations of invitees, and the draft research papers shared at the national workshop.

National River Linking Project: Analyses of Hydrological, Social and Ecological Issues

Overview of the Workshop Proceedings

Upali A. Amarasinghe and Bharat R. Sharma
International Water Management Institute, New Delhi, India

Introduction

Coping with annual floods and droughts, both occurring at the same time in different parts, has been a major concern for India over the millennia. These concerns are more acute today as the growing population and the resultant increase in water demand place a heavy burden on the unevenly distributed water resources, and also cause huge economic losses to the financially vulnerable groups of the population. Additionally, there is a huge demand to enhance and diversify food production to meet the needs of a vast population with changing consumption patterns and higher disposable incomes. Designed to address these concerns, the National River Linking Project (NRLP) envisages transferring water from the potentially water surplus Himalayan rivers to the water-scarce river basins of western and peninsular India (NWDA 2006). The NRLP will build 30 river links and approximately 3,000 storages to connect 37 Himalayan and peninsular rivers to form a gigantic South Asian water grid. As Tushaar Shah et al. (Paper 1 in this volume) have pointed out, the NRLP concept perhaps originated at a time when there was stiff opposition to large dams. Environmentalists questioned the ecological cost of large dams, while the NGOs and civil society probed the social cost of people displacement. However, much of the discourse on the NRLP to date is filled with opinions and assertions, but many of the arguments for and against the project have little analytical rigor. The International Water Management Institute (IWMI) and the Challenge Program on Water and Food (CPWF) have designed a 3-year project titled 'Strategic Analysis of India's River Linking Project' to qualitatively improve the issues and direction of the present NRLP debate (IWMI 2005).

The primary focus of the IWMI-CPWF project is to provide the public and the water resource and policy-planners with a balanced analysis of the pros and cons of the NRLP components. The IWMI-CPWF study, 'The Strategic Analysis of India's River Linking Project', assesses India's water future from 2025 to 2050 and analyzes alternative options, including the River Linking Project, and their adequacy to meet the demands of the proposed water future. The specific objectives of the project are to:

- Assess the most plausible scenario of water supply and demand given the present trends of the determinants of water demand;
- Analyze whether the NRLP concept can be an adequate, cost-effective and sustainable response in terms of the present socioeconomic, environmental and political trends, and if implemented, how best the negative social impacts can be mitigated; and
- Prepare a plan of institutional and policy interventions as a fallback strategy for the NRLP and identify the best strategies to implement alternative options.

Phase I of the project focused on analyzing India's water future scenarios from 2025 to 2050 and the related issues. Phase II, which is ongoing, analyses aspects of social cost: benefits associated with NRLP without attempting a full social cost-benefit analysis. Based on the findings of the earlier phases, Phase III will explore alternative strategies for ensuring India's future water security. Due to the paucity of information on many of the proposed links, Phase II's assessment is conducted in two tracks. Research in the first tack assesses how NRLP as a concept can be socially acceptable and to what extent NRLP can contribute to meeting the water demand scenarios of the nation. Studies in the second track analyze the social cost-effectiveness of the few proposed river links. Under this track, we have selected the proposed Polavaram-Vijayawada and Ken-Bethwa links of the NRLP, and the existing IGNP canal project for detailed analysis. The social cost-effectiveness analysis of the links includes assessing:

- Direct and indirect benefits of irrigation water transfers;
- Groundwater externalities of surface water transfers;
- Gender impacts and equity issues of new water transfers;
- Benefits of domestic and industrial water transfers;
- Environmental benefits and 'dis-benefits';
- Hydrological feasibility; and
- Resettlement and rehabilitation issues of large water transfers.

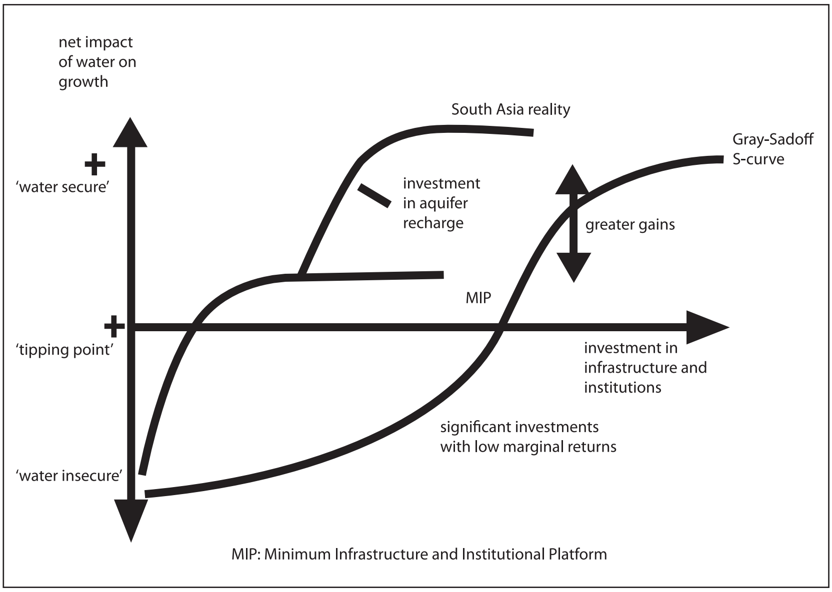
The studies conducted so far have generated a large number of outputs of relevance for policymakers and the public. The major objective of the national workshop was to share the results of various research activities conducted in Phases I and II of the project, and add value to the ongoing debate on this subject, which remains of great importance to India and the region.

This paper presents an overview of the keynote speeches and presentations of the first national workshop. Sections one and two are a summary of the keynote speeches presented at the inaugural session. The issues related to hydrological feasibility of water transfers are discussed in section three, benefits and cost of irrigation water transfers in section four, implications of improvements in rain-fed agriculture on NRLP water transfers in section five, contingencies for large inter-basin water transfers in section six, groundwater irrigation and future direction in India in section seven, issues of resettlement and rehabilitation in large water transfer projects in section eight, and transboundary issues of water transfers in section nine. We conclude this paper with an overview of the major issues raised in the discussions of the workshop.

Inaugural Session

The economic growth of a country is critically linked to water security, for which substantial investments are required. The Model by Grey and Sadoff 2005 (Presentation 1 of Tushaar Shah), which influenced the thinking of public investments in the past, suggests that poor countries require investments in water resources development that reach tipping point in order for these to yield positive returns. After a country reaches the tipping point the returns to investment increase, and after a country reaches a reasonable level of water security the returns to investment taper off.

Figure 1. Dominant view of public irrigation investments and returns (Grey-Sadoff model), and South Asia investment patterns.



Source: Tushaar Shah's presentation 1 (see annex)

Many poor countries will have to invest several times more than their Gross Domestic Product (GDP) value in order to reach the tipping point. However, due largely to low-cost private investment, in South Asia in general, and in India in particular, investments have already reached this tipping point. As a result additional public investment in canal irrigation in these countries now yields little returns. For example, India invested close to Rs. 100,000 crore (US$24 billion in 2006 prices) in surface irrigation since the early 1990s, but it has hardly resulted in any addition to the net irrigated area. However, use of groundwater, which is primarily private due to the source of investments, dominates irrigation now and is expanding further. Countries such as India, require re-thinking in their public investment strategies to shift the returns to an upward direction. The present trends of development indicate that the major challenges for India in the future lie in managing the colossal groundwater economy.

Similar sentiments on the management of groundwater resources were echoed by Prof. M. S. Swaminathan in his inaugural address. Declining returns from past public investments in canal irrigation sector indeed raise many serious issues concerning ‘India’s Water Future’. Many a time, the performance of the irrigation sector in India tends to be measured by the quantum of total investment. However, even after huge investments many areas are still under agrarian distress. Irrigation is one of the important components of the relief packages to areas of agrarian distress. Yet, even after substantial investments, poor performance of the canal irrigation sector remains a grave concern. Statistics of irrigation potential are often overestimated for purposes of obtaining project approval, resulting in a substantial gap with the actual irrigated area. In this context, it is of concern how the 10 million ha of new irrigated lands can be created under the proposed Bharat Nirman Program, let alone the proposed 34 million ha under the NRLP. Although not much research has been conducted on these issues, a substantial part of this additional area could also come from groundwater irrigation. In such a scenario, rainwater harvesting and aquifer recharge become important and necessary. Given its contribution to irrigation and also to drinking and industrial water supplies, augmentation of supply and management of demand of groundwater are important.

Accoding to Prof. Swaminathan, given the importance of local level water harvesting and aquifer recharge, grassroots level institutions could play a major role in addressing problems related to water, for which these organizations should be empowered with better knowledge and technology, and sound financial and legal frameworks. Two recent initiatives of the Ministry of Water Resources can contribute immensely to improve rural livelihoods through local planning. The first initiative is the ‘National Water Year Award’. Last year this was awarded to Hiware Bazar (Box 1), which is a classic case of how locally managed organizations can transform villages through better planning. Many National Water Awards, such as the one awarded to Hiware Bazar, could have significant uptake and impacts.

Box 1. Water Budgeting in Hiware Bazar

Hiware Bazar, a village in Ahmedngar district of Maharashtra, with slightly over 400 mm of rainfall, frequent droughts and degraded environments, is faced with an acute shortage of water. To regenerate its once rich natural resources base and to address current water scarcities, Hiware Bazar Panchayat has created a village level water budget. The village water budget first estimates water availability and then plans the allocation to different users. The local participatory democratic organization, called Gram Sabha, approves these plans, which then become law for the local people. These plans have helped Hiware Bazar recharge its wells, to increase from single to double cropping, to have stable production, and to increase income by 20 times over the last 10 years.

The second initiative is the 5,000 small experiments conducted by 61 agricultural institutions at 1-2 ha level, for improving water productivity. It is imperative to examine how these unique experiments, and also experiences such as Hiware Bazar, can be out-scaled to other areas or regions and up-scaled to bigger area or community units to achieve larger results, like more crop per land where land is scarce, more crop per drop in water-scarce situations, and more crop per drop of diesel in the context of the emerging energy crisis.

According to Prof. M. S. Swaminathan, three important requirements need recognition in the future: 1) Water literacy - education and awareness of the efficient use of scarce water supply, especially given the wastage of water by the affluent ; 2). Social mobilization, where democratic grassroots level organizations that are empowered with knowledge, technology and financially and legally, can play a major role in water management, especially rain water harvesting and managing groundwater in a scientific way; 3) Regulation, which can be used as an instrument in reducing over-exploitation of the resources. These initiatives are important in the context of integrated water resources management at the basin level meeting India's future water demand.

What then is the role of large water transfers such as the National River Linking Project in meeting the future water demand? In his inaugural address, Mr. Suresh Prabhu cited two extreme opinions in the present discourse on NRLP. Both proponents and opponents think that the country will be doomed depending on whether NRLP is not implemented or implemented. In many instances independent analyses of large water transfers are lacking. In this respect, the analysis of IWMI is timely and could contribute to a proper evaluation of the NRLP process. Mr. Prabhu, however, emphasized that it is important to accept that India is having serious problems relating to water. These problems will only be aggravated by an increasing population, especially by an increasing young population. The acceptance of existing and also of impending problems relating to water could help people to think through and analyze the process, and arrive at a logical conclusion. Such an analysis needs a holistic approach.

Every human intervention has ecological consequences. Therefore, analysis of water developmental projects should not only assess direct benefits such as hydropower generation, irrigation, groundwater recharge, transportation, employment generation etc., but also assess ecological cost, social and political cost, and the impact of international implications. Such a holistic analysis should also include:

- Investigating the potential for up-scaling of micro level water management, such as the case in Hiware Bazar, and their implications;
- Conducting scientific analysis of groundwater availability, use, management and of future potential;
- Assessing reasons for the gap between irrigation potential that is created and utilized, and the potential for increasing the efficiency of existing irrigation systems; and
- Exploring suitable/ optimum cropping patterns for different regions of the country.

Furthermore, such an analysis should also consider projects that are already undertaken by different ministries. While the Power Ministry initiates various projects to harness the 150,000 MW potential, the Water Resources Ministry is undertaking projects to increase the irrigated potential. In addition, the Forest Ministry conducts forestation activities and the Rural and Urban Development Ministries augment the water supply to meet domestic drinking and municipal and industrial demands. A holistic analysis in the water sector should consider all these factors and results and indicate further requirements for meeting India's water and hydro-power futures. Only a comprehensive analysis of these complex interacting problems can provide scientific solutions and provide the options that India requires to face the serious challenges in the water sector. Such solutions will not only help the national and state governments, but also cities, communities, households and farmers to make proper decisions on water development and management.

India's Water Future: Scenarios and Issues

Increasing demand for water at global, regional, national and local levels has received significant attention in recent studies. The 'water future' assessments of the recently concluded Comprehensive Assessment of Water Management in Agriculture highlighted many issues of global and regional importance (Paper 2 by Upali A. Amerasinghe et al)). Growing population, increasing income and urbanization, and associated changes in consumption patterns, especially with increasing income in developing countries, are changing the pace of water demand patterns. Along with changing patterns of food consumption and production, the increasing water demand in domestic and industrial sectors is changing the pattern of water use in developing countries.

India is no exception to these changing patterns in the drivers of water supply and demand (Paper 2 by Upali A. Amerasinghe et al.). While demand for cereals in India has been decreasing since the early 1990s, the demand for non-grain crops and animal products has been increasing. As a response to the changing patterns of internal demand and also to the increasing export opportunities under global agricultural trade, cropping patterns in both irrigated and rain-fed areas are diversifying. Groundwater has been the major source of water supply for irrigation in the last two decades. Business-as-usual trends indicate that groundwater will continue to be the major source of water supply for irrigation, and the share of water withdrawals for domestic and industrial sectors will increase much faster than that for irrigation. However, the business-as-usual water use patterns will increase unsustainable water-use patterns, which will lead to water crises in many river basins in the country. Both, supply augmentation through groundwater recharge and irrigation demand management are two areas of immediate importance.

Water supply and demand scenarios of the Godavari (Polavram)-Krishna (Vijayawada) link canal under the NRLP water transfers are the focus of Paper 3 by Luna Bharati et al. This study addressed the implications of alternative cropping patterns on the water demand in the command area and outside. Proposed water transfers and use would affect the downstream water users in the Godavari delta reservoir, and will not be able to meet the environmental water demand in the Krishna Basins. The study suggests that water resource development in the region should take into consideration the monthly variations in planning of water resource development.

The discussion of this session highlighted that developing countries need to seriously consider and prioritize their investments in development , utilization and management of water resources, study the scaling implications and institutional requirements for wider dissemination of micro-level successes in water resources management, consider the environment and the project-affected people as important stakeholders in the planning, and identify potential interventions required to be adopted and take suitable action to increase the productivity of water by following environmentally-benign technologies.

Hydrological Feasibility of Large Water Transfers

The main objective of this session was to discuss issues relating to the hydrological feasibility of large water transfers, such as NRLP, in India. Anil Mohile's (Presentation 3) keynote address noted the rationale for the planned water transfers in the NRLP project given the situation in the 1970s and 1980s; changes of key parameters in recent years, and the feasibility of proposed links under the changing socioeconomic scenarios. National food security, agriculture dominated economy, lack of electric power in rural areas, imbalance in international trade and strong regional and national view points were among the key drivers that justified the NRLP concept. But many of these key drivers and also agricultural water use practices have changed or are in the process of changing. Agriculture no longer dominates the economy, and agricultural demography is also fast changing. Groundwater is a major source for meeting agricultural water need, and the agriculture sector does not necessarily have priority over other economic sectors and the environment in water use. However, water scarcities are increasing in many regions and concerns do still exist as to the inequitable distribution of water in different regions and as to national food security. In light of these concerns many of the proposed links would generate significant benefits and attract medium to low inter-state and international concerns for implementation.

Paper 4 by Vladmir Smakhtin et al. analyzed the hydrological feasibility of proposed water transfers through the links in the NRLP that flow into and out of the Krishna River Basin. This study suggests that the use of annual flow data, as indicated in the feasibility reports, may show that more water is perceived to be available for transfers at the respective site. If the environmental water demand, such as that which is critically required for the delta areas of the Krishna Basin, is also taken into account, the perceived water surpluses may further be reduced. The study suggests that intra-annual variability of water availability and environmental water requirements need be to taken into account in assessing the hydrological feasibility of large water transfers.

Shah and Kumar (Paper 5) discussed the issues and controversies associated with the feasibility assessment of small and large dams. According to this analysis, the present criteria of classifying large dams according to the height of the dam, is not appropriate. The existing criterion often overestimates the social and environmental cost, which often leads to substantial interest and debate. It also leads to a significant underestimation of the indirect social and economic benefits that large dams generate. This paper argues that the new classification criteria could better assess the benefit and cost of large dams.

Cost and Benefits of Irrigation Water Transfers

The economic cost and benefits of past irrigation investments and also of the proposed water transfers were the focus of this session. The study by Inocencio and McCornick (Paper 6), which is based on a global data set of 314 water development projects, included 37 projects from India that showed that although the economic performance of surface irrigation projects is increasing globally, it has been declining in India in recent years. However, large projects with many small schemes, projects with diversified cropping patterns, and projects that are farmer-managed and others managed by water user associations tend to have a higher economic performance. The finding of this study is indeed revealing in the light of the huge investments made and the decline in the canal irrigated areas in recent years.

Anik Bhaduri et al. (Paper 7) and Upali A. Amarasinghe et al. (Paper 8) estimate the economic benefits of the proposed water transfers in the Godavari (Polavaram)-Krishna (Vijayavada) and the Ken-Bethwa links of the NRLP. A major part of the proposed command area in both locations is already irrigated.

The study by Anik Bhaduri et al. (Paper 7) shows groundwater irrigates more than 90% of the command area of the Godawari-Krishna Link at present. Thus, the additional net value added as economic benefits per additional cubic meter of proposed water transfer, is estimated to be low. However, a substantial part of the command area has declining watertables due to overabstraction of groundwater, and is presently a constraint for further diversification and economic growth in the command area. The proposed water transfers will assist more diversification to high-value annual crops and recharge the depleting groundwater tables in the command area.

The study by Upali A. Amarasinghe et al. (Paper 8) noted the importance of local level hydro-meteorological conditions and patterns of crop production in the planning of local level water transfers. Monsoons provide much of the rainfall in the Ken-Betwa link command area, thus, hardly any area is irrigated during the kharif season. However, a substantial part of the irrigation transfers is proposed for the kharif season. Moreover, rice is a major part of the proposed cropping pattern, whereas rice cultivation in this area, even under irrigation conditions, has decreased significantly in recent years. The study shows that the direct and indirect benefits per every cubic meter of water consumed or delivered is rather low even under the most optimistic scenarios of cropping patterns. The results of this study once again reaffirm the importance of giving due consideration to interests conducive to local conditions.

Amrita Sharma et al. (Paper 9), while analyzing the impact of irrigation water transfers on gender and equity', made a deliberate deviation, looking at different types of impact on irrigation within the command areas of a canal project. The benefits of irrigation are utilized differently across different communities, depending many a times on the social, political and financial capital of different communities. The existing inefficiency in water supply management and poor supervision from the irrigation authorities and WUAs have made the head-tail divide much sharper. The rapid land transactions altered significantly the social geography of the area during the initial period of the study. While some communities with more social and financial capital are able to move up the economic order, many other landless people could not get adequate benefits. Thus, with the prevailing poverty situation, irrigation interventions have made little dents on unequal gender relationships. There is a little change in women's access to and control over key primary assets and with little impact on their personal lives and decision-making capacity.

Future of Rain-fed Agriculture – Implication for NRLP Water Transfers

Rain-fed agriculture covers 60% of the present crop area in India but contributes to only one-third of the crop production. Improving productivity could significantly increase crop production from the existing rain-fed areas and in turn reduce requirements for large scale intra- and inter basin water transfers for irrigation. Dr. J. S. Samra, Chairman of Rain-fed Agriculture Authority of India explained its role in improving agricultural productivity under rain-fed conditions (Presentation 4). The importance of supplemental irrigation in critical periods of water stress for higher crop yields, opportunities of runoff water harvesting and recycling of water for supplemental irrigation on crop yields are vital areas of research and development for the Indian rain-fed agriculture.

Bharat R. Sharma et al. (Paper 10) showed that the productivity of rain-fed areas is indeed hampered due to mid-season and terminal droughts. Supplemental irrigation in these critical periods can significantly increase yields of many rain-fed crops. In large parts of rain-fed areas, water availability is not a constraint for supplemental irrigation. This analysis shows that 28 M ha of rain-fed lands, which can benefit from supplemental irrigation, generate about 114 billion cubic meters of runoff annually. Only a fraction of this runoff can provide critical supplemental irrigation to 25 million ha of crop lands during normal monsoon and 20 million ha during the drought seasons. Provision of this harvested water through one supplemental irrigation during the later stages of crop growth has the potential to enhance rain-fed production by more than 50 %.This analysis shows water harvesting for supplemental irrigation in rain-fed lands is indeed economically viable and socially equitable, and could have little negative impact in the downstream. Potential benefits are much higher for oilseeds, pulses and rain-fed rice areas as compared to coarse cereal areas.

Contingencies that Could Justify Large-scale Water Transfers

It is argued that uncertainties associated with international trade and the requirements for national food self-sufficiency, increasing use of biofuel and the associated increase in irrigation water demand, essential requirement of reliable water supply for crop diversification in high-value crops, the energy crisis and its impacts on smallholder farmers using groundwater, depleting groundwater tables in basins that are reaching closure, constraints for large-scale groundwater recharge in hard rock regions and increasing demand and willingness to pay from domestic and industrial users in exchange for reliable surface water supply, are several contingencies that could justify large-scale water transfers between basins. This session focuses on a few of the aforementioned important issues.

Prof. Y.K. Alagh (Presentation 5) discussed how international trade can be used to avert large- scale water transfers between basins. Although internal demand is a major driver of crop diversification in India, international trade can increase this process. This kind of impetus on crop diversification will also increase pressure on water and land availability. However, the trading trends between agricultural agroclimatic regions were the ones which often encouraged the implementation of sustainable land and water management policies. There can be considerable synergy between trade, diversification and sustainable development. However, the present agricultural policies of India are not conducive to a trading environment, which is dominated by the WTO and also confounded by highly distorted global agricultural markets.

A major part of the present agricultural exports includes horticulture, dairy products and spices, most of them grown on drylands. However, the present crop diversification that is followed in many irrigated lands ignores these opportunities. The main crop diversification now includes switching to high-value cereal crops and following it up with non-cereal food or non-food crops. However, fodder or tree crops or horticulture in some areas, while improving trading opportunities, will decrease pressure on the demand for water.

More than 15 million smallholder groundwater irrigators in India, of which many are water buyers, are under siege from an energy squeeze. Deteriorating farm power supply, increasing difficulty in acquiring new electricity connections and an eight-fold increase in prices of diesel, contribute to this squeeze. Surface irrigation is an alternative to this crisis, but that may require large water transfers. Tushaar Shah (in Paper 11) discussed the trends of recent energy prices, the energy crisis in agriculture and of the coping strategies adopted by small landholder irrigators in India. Increases in diesel prices and pump irrigation charges by six to eight fold in the last four decades have far exceeded the increases in prices for food crops. In the 1990s, selling one kg of wheat was sufficient for purchasing one liter of diesel. Today, it costs three to four times more than that amount to purchase a liter of diesel. The demand for groundwater irrigation is highly elastic to the irrigation cost. Energy squeeze is a major cause of severe agrarian distress, especially among the landless smallholder water buyers. Coping strategies to minimize the impact of the energy squeeze at present include diesel saving crop substitution or return to rain-fed farming; energy substitution of PDS kerosene to diesel and/or using low-cost Chinese diesel/kerosene pumps; adopting energy-saving irrigation practices or shifting to high-value and high-risk crops; and as a last option, an exit from unviable farming. Promoting fuel-efficient Chinese diesel/kerosene pumps, subsidizing diesel or providing rations for kerosene, increasing power supply or providing a separate electricity supply for agriculture, and targeting electric supply to poor or cooperative electric tubewells could ease the present agrarian distress.

Surface irrigation is a major source for recharging groundwater and that in turn mitigates problems relating to the downward trend in the groundwater tables of water-scarce regions. However, positive and negative externalities of groundwater recharge in surface irrigation systems are often underestimated. The study of the Godavari (Polavaram)-Krishna (Vijayawada) Link of the NRLP by Bharat R. Sharma et al. (Paper 12) discussed the externalities of additional water transfers. The study also projects that surface irrigation in the Godavari-Krishna Link command would raise the groundwater level on average by 2 meters, and improve the groundwater profile from over-exploited to semi-critical blocks in the Krishna Basin. However, at the same time 16% of the command area could also be at risk of waterlogging. In addition, the study suggests that conjunctive water use with the existing infrastructure and with appropriate cropping patterns could mitigate waterlogging and, thus increase the economic benefits.

Rainwater harvesting and artificial groundwater recharge are proposed as possible alternatives for large surface water transfers. Dinesh Kumar et al. (Paper 13), however, highlighted the limited opportunities that exist for rainwater harvesting and artificial recharge in the many arid regions of India. Low quantity and highly variable rainfall, fewer rainy days, high evaporation and hard rock geology in many water-scarce areas are the major limitations in the supply side. Due to high demand, many river basins in water-scarce areas are facing closure now. As regards these basins, the economic value of water is high in water-scarce areas vis-à-vis water surplus upstream catchments. Therefore, attempts to change hydrological impacts upstream could have severe economic impacts in the downstream regions. The study also noted the high unit cost of water harvesting associated with many known techniques. A better understanding of surface and groundwater and upstream and downstream interactions of water supply in a basin, basin-wide water accounts, and of the cost of various techniques for different environments, are necessary for designing cost-effective programs of water harvesting.

Groundwater Irrigation – Future Directions for India

Groundwater was the major driver of irrigation expansion in the past, and is the source for more than 60 % of the total irrigated area at present. This trend seemed to continue unabated albeit at a slower rate of growth. Mr. Jha, Chairman of the Central Ground Water Board, shared the vision of future direction and policy issues (Presentation 6). Due to an unprecedented increase in groundwater abstraction, the depth of groundwater in many regions is at a threateningly low level. About 30 % of the 5,723 assessment units are either over exploited or at critical to semi-critical levels. This includes much of the breadbasket of India—especially in the states of Punjab and Haryana. The present rate of abstraction of groundwater could even impact the food, health and environmental security of these regions, in particular, and the whole nation, in general. It is imperative that many effective policy measures are implemented quickly to avoid a widespread crisis. These policy options include: regulatory mechanisms for curtailing groundwater exploitation in the over-exploited areas; demand management strategies for reducing abstraction, which includes pricing, spreading micro-irrigation techniques, providing a reliable electricity supply etc.; supply augment measures through artificial recharge; plan for ownership and allocation of groundwater among different sectors; and judicious planning of groundwater abstraction in under-exploited areas in the flood-plain aquifers, alluvial plains in eastern and north- eastern India, and in the coastal areas.

In spite of the limitation illustrated by Dinesh Kumar et al. (Paper 13), artificial recharge movement has a long history in India and is argued to have a significant potential for restoring depleted resources and thereby improving groundwater irrigation. R. Sakthivadivel (Paper 14), speaking on “Decentralized Artificial Recharge Movements in India: Potential and Issues”, showed the extent of artificial recharge movement in the country and the techniques of recharge, national status on artificial recharge technology, economic and environmental impacts, and cost of artificial recharge. This paper argues that a substantial part of the future water demand can be met from artificial and wastewater recharge. Sustainable groundwater recharge programs are necessary to reap the full benefits of artificial and wastewater recharge. Thus, groundwater recharge programs should be participatory where communities are involved in the planning and management of groundwater resources. The paper also suggested a systematic research program for identifying potential areas for artificial groundwater recharge and their benefit and cost.

Tushaar Shah and Shilp Verma (Paper 15) discussed a possible demand side management strategy for groundwater overdraft. In 2002, IWMI, in its studies, argued that intelligent rationing of an electricity supply is the second best option to full metering. It suggested to separate the electricity supply given to tubewell farmers, provide electricity according to a pre-announced schedule, provide high-quality power supply during the peak irrigation demand periods of about 30 days and reduce the supply to 4-5 hours per day during the rest of the period, avoid metering cost for now, but gradually increase the flat tariff to meet the average cost, and enforce stringent controls on the new electricity connections and pump sizes. 'Jyotirgram Yojana', is the Government of Gujarat's response to management of groundwater over-abstraction, in which they separated the power supply to farm tubewell irrigators and the non-farm sector, and implemented all but one of the IWMI recommendations. Today, the non-farm sector in Gujarat receives 24 hours of power supply, and the tubewell irrigators receive 3-phase uninterrupted power supply for 8 hours per day. 'Jyotirgram Yojana' is a successful effort on demand management in Gujarat, and an improved version with modifications will offer a way to reverse rural de-electrification in eastern India at a moderate cost.

Rehabilitation and Resettlement Management in Large Dam Projects in India: The Lessons for India

Resettlement and rehabilitation (R&R) of involuntarily displaced populations continue to be a difficult problem, despite the vast national and international experiences in R&R, and the existence of several guidelines on resettlement management. Many attribute this to the limitations of policy guidelines and institutional limitations. This session, while acknowledging these limitations, deviated from a traditional analysis of issues relating to R & R. It discussed the long-term impacts of R&R by analyzing the new livelihood opportunities created by new water development projects and which displaced people benefited from these projects.

Ramaswamy Iyer, former Secretary to the Ministry of Water Resources of India, illustrated the changes that are under consideration in the new policy on R&R. According to his opinion emerging enlightenment was reversed by the pursuit of growth and development accompanied by impatience with other concerns. He regrets the loss of a sense of justice and compassion, and outlined an approach to a more humane and equitable policy on displacement and rehabilitation.

The study by Madar Samad and Zankhana Shah (Presentation 7) shows that enhanced livelihood opportunities in relocation sites can create longer-term benefits that compensate the short-term losses associated with such resettlement schemes. The study also tests the hypothesis that with proper risk management policies, the short-term negative impacts of the livelihood of displaced people can be fully averted in some cases and largely arrested or to some extent mitigated in others. In these cases, livelihoods of resettled people are restored quickly to those levels at which they were before displacement. The study findings are based on field studies of the resettled population in Ujjani project in Maharashtra and Sardar-Sarovar project in Gujarat and Maharashtra. The hypotheses have been proven true for the 'oustees' in Gujarat, but their success in Maharashtra and Madhya Pradesh lagged in propensity. Although 'oustees' in Gujarat have encountered a period of initial stress and a decline in their standard of living, a majority of them have restored their livelihood to that of the pre-displaced level within 4-6 years. Unlike other states, Gujarat has a unique mechanism for acquiring agricultural land for replacement at market prices, and also has a special agency for implementation. In addition the state has well-developed special units for monitoring the resettlement and rehabilitation process. This study, although discourages forced displacement, adds a new dimension to the discourse on R & R of 'oustees' of major development projects. It reveals that not all is bad for R & R 'oustees', contrary to what is frequently highlighted in many large water transfer projects.

Transboundary Conflicts in Water Transfers

Water transfers in the Himalayan component of the NRLP are saddled with issues and conflicts relating to transboundary water diversions. However, many lessons can be learned from existing international agreements. Gichuki and McCornick (Paper 16) highlighted international experiences from agreements on using water in the Aral Sea basin among Central Asian republics, and water transfers between Tagus and Ebro basins in Spain. Much of the initial agreements of water sharing are no longer functional in these basins, and many conflicts have arisen recently. Many of these conflicts are due to the unforeseen circumstances at the time of formulating the initial agreements. Thus, a holistic analysis of the water supply, its use and the future demand for it in different countries in a river basin could reduce these conflicts to a minimal.

Can existing agreements also be modified to augment water supply by transferring more water between basins? A classic case is the agreement between India and Bangladesh on sharing the Ganga's water. Under NRLP, surplus water of the Brahmaputra River is expected to be transferred to the Ganga basin to facilitate further transfers to the peninsular basins. Anik Bhaduri and Edward Barbier. (Paper 17) suggest that existing agreements can be modified to augment water supply, which in turn will benefit both countries. However this depends on the political altruism of India to transfer water to a downstream country such as Bangladesh. In the absence of political altruism, and if India unilaterally diverts water to her peninsular basins, Bangladesh would incur huge environmental losses.

This research is still at an early stage and more work is required for quantifying the water transfers that entail a win-win situation for both countries, under many forms of possible contingencies. However, the study by Bhaduri et al. shows how two countries can transfer water between basins and benefit both if the up-stream country has political altruism to transfer water to the down-stream country or have sound legalistic insurance mechanism in place to safeguard the downstream country in the event of a negation in altruism.

Conclusions

It is indeed important to acknowledge, as many participants of the workshop agreed, that if business-as-usual trends continue, India will face a severe water crisis. Inter-basin water transfers could certainly be a solution for water-scarce regions in peninsular India. However, the research conducted under this project, although raised many important issues, did not provide precise estimates of the quantity and the locations that can benefit from these water transfers. The discussion on the need for expanding surface irrigation was always overshadowed by the poor returns to investments in this sector. The colossal investments in the canal irrigation sector in the recent decades had hardly any impact on increasing the surface irrigated area and promoting diversified agriculture. It is indeed intriguing why such stagnation or in some areas declining trends of surface irrigated area continue. Most likely poor management of the created infrastructure, inefficient water institutions at various levels and economically unviable political policies in the water sector are the factors that lead to such a situation. In order to know the need for further surface water transfers, it is imperative to accurately assess the reasons for such underperformance in the canal irrigation sector, and the potential of other supply augmentation and demand management strategies in the existing irrigation infrastructure. There are no disagreements that groundwater, as in the past, will play a major role in shaping India's Water Future. In fact, much of the proposed irrigated area, as in the Godavari-Krishna and Ken-Betwa, under the NRLP is already irrigated through groundwater. Many argued that harnessing the excess runoff through water harvesting and artificial groundwater recharge can provide supplemental irrigation for the rain-fed areas as well as sustain the groundwater irrigation in others. But, equally strong arguments are made that the potential for artificial recharge, especially in the water-scarce arid regions of India, is low due to vagaries of rainfall. And water harvesting, artificial recharge and upstream development in water-scarce basins can have a significant negative economic impact on downstream users. However, it is not clear where exactly and in what magnitude these negative impacts occur in India. This requires a thorough investigation. Studies also show micro irrigation, resource conservation technologies and other water saving technologies can contribute substantially to demand management and productivity enhancement as well.

Change in consumption patterns and fast economic growth in large parts of the country require a shift in cropping patterns with much greater attention to diversified agriculture and animal/ fisheries based products. All this requires precise and reliable water supplies, especially for the smallholder farmers, located closer to the cities and towns. Supplies from groundwater and treated wastewaters have the potential to meet these fast growing demands. Additionally, the domestic and industrial water demands are expected to grow substantially resulting in high opportunity costs to meet the additional investment requirements. Future large, water transfer projects must make an adequate allocation to meet these demands. In fact, the Godavari-Krishna Link's left bank canal has been designed mostly to meet the growing domestic and industrial demands of Vishakhapatnam city.

Productivity enhancement is also mentioned as a critical tool for reducing further irrigation expansion. Estimates show only less than half of the water withdrawals are depleted beneficially at present. It is also true that although irrigation was a major determinant of productivity growth in India, the growth of yield has begun to decline in recent times. Therefore, it is important to identify locations of low productivity and high potential areas and where interventions for increasing the water productivity are required. Rain-fed agriculture shall continue to play an important role in meeting the existing and future food demands, especially relating to oilseeds, pulses, rain-fed rice and coarse cereals. Presently, in addition to the levels of productivity being low, the vulnerability of the farmers dependent on it is quite high. Improving productivity in rain-fed agriculture, with a small quantity of supplemental irrigation, is shown to have significant potential.

Assessment of available water surplus in river basins should also receive significant attention. Future water requirements of different water users within the basin, whether for irrigation, domestic or industrial uses and most importantly for the downstream riverine environment should be assessed before deciding the surplus. Presently, in the entire discourse on water resources development, environment is a silent stakeholder. Equally important is to consider water availability at shorter time periods, at least monthly for evaluating the water availability. In the absence of such an analysis, more water is perceived to be available for transfers at different locations.

When water is proposed to be transferred across the basins, on most occasions the interests of donor and the recipient regions (states/ countries) are at conflict and need to be resolved through innovative win-win solutions. In the absence of mature and experienced river basin organizations and well-established sharing mechanisms, the issues involved are sure to become more complex than the hydraulic structures and, have the potential to become the first stumbling block in the process of water transfer. The associated and equally important issue is the properly designed, disseminated and implemented rehabilitation and relief package for the project affected people. As the land is becoming scarce and valuable and civil society organizations more vocal and effective, the acquisitions must be handled with great sensitivity, tact and empathy.

References

IWMI (International Water Management Institute). 2006. Strategic Analysis of India’s National River Linking project (NRLP). Proposal accepted by the CGIAR Challenge Program on Water and Food. Available on line http://nrlp.iwmi.org/PDocs/PrjProposal.asp.

NWDA (National Water Development Agency). 2006. “The Need”, www.nwda.gov.in.

India’s River Linking Project:
The State of the Debate[1]

[1]*Tushaar Shah,* [1]*Upali A. Amarasinghe and* [2]*Peter G. McCornick*
[1]*International Water Management Institute, India*
[2] *International Water Management Institute, Sri Lanka*

Introduction

For a people reveling in discord, Indians have become increasingly united when it comes to sharing the dread of their water-scarce future. Also visible with this growing concern is a rapidly spreading sense of disenchantment towards the inadequacy and apathy of governments in dealing with recurrent cycles of flood and drought, occurring simultaneously in different parts of the country. So when the President of India, in a speech addressed to the nation on the eve of Independence Day 2003, declared, “The first mission (of my government) is on the Networking of Rivers … This will eliminate the periodical problem of droughts and floods ... and provide both water and power security”, he was addressing this popular concern directly.

For a long period of time, the notables in India have argued that the answer to the drought-proneness of western and peninsular India lies in the flood-proneness of the east, and vice versa. Sir Arthur Cotton, who restored the Grand Anicut on the Cauvery and has remained a cult figure in the Deccan villages since the early decades of the nineteenth century, had thought of a plan to link the rivers in southern India for inland navigation. More recently during the mid-1960s, Dr K.L. Rao, a well-respected technocrat, presented a crude proposal for a Ganga-Cauvery Link from a point below Patna. A few years later, Captain Dastur, a pilot, speculated aloud about a lateral Himalayan canal from the Ravi to the Brahmaputra along a constant 400-meter contour interconnected with a Garland Canal girdling peninsular India. But ideas like the Garland canal and the Ganga-Cauvery Link were routinely dismissed as too grandiose for a resource-strapped nation. The Indian psyche was, however, never fully disassociated with the idea; Prime Minister, Mrs. Indira Gandhi constituted the National Water Development Agency (NWDA) to start detailed planning of a mega-project, which no one imagined would ever leave the drawing board.

Implementing the mega-scheme, which required pre-feasibility studies, feasibility studies, environment impact studies and the like, was destined to be a long, drawn out process. But in 2003, acting on an innocuous petition from a lawyer, the Supreme Court of India decided that

---

[1] Draft prepared for a book volume of the RFF Press water policy series.

the time had come for the nation to pull its act together on the water front, and enjoined the Government of India to complete all planning required to launch the River Linking Project by 2006, and to complete the project itself, by 2016. Without losing time, Prime Minister Bajpai of the then ruling National Democratic Alliance (NDA) government—who had so far been an avid advocate of local rainwater harvesting - constituted a high-powered, multi-disciplinary task force to embark upon the Project forthwith and asked Suresh Prabhu, a young, highly regarded minister, to lead it. Many expected the idea to be dropped on the wayside when the NDA government fell. Moreover, a groundswell of opposition had emerged from environmental groups and civil society organizations that have begun to question the basic model of water resources planning and management through the use of large-scale dams and canal networks. The new United Progressive Alliance (UPA) government has waxed and waned the mega-project; however, it is hard to tell when the idea will rise from its ashes like the phoenix and bestride the Indian discourse on water scarcity like a colossus.

Resuming the Global Experience

Even as India has been procrastinating, the rest of the world has gone ahead with inter-basin water transfer (IBT) projects at a brisk pace during the past 50 years or so. Global and local opposition notwithstanding, China has steadfastly stayed on course in its own scheme of transferring 48 km^3 of water from the Yangtze River to the Yellow River to improve water availability in the dry plains of North China. Elsewhere in the world, many IBT projects have faced a variety of problems and produced some unwanted side-effects; however, in overall terms, most have turned out to be beneficial on balance. Even a wary global environmental review of IBTs (Snaddon, Davis and Wishart 1999), which advocates using precautionary principles, concluded that:

> *"In many parts of the world, water transfers have become the lifeblood of developing and extant human settlements, for which no alternative is currently perceived to be available."*

If an IBT is viewed as 'the mass transfer of water from one geographically distinct watershed to another' (ibid), IBT has been the central theme in the story of human development over the last 6,000 years. Inter-basin water transfers are nothing new, even in India. Colonial irrigation works in the Indus and Ganga basins were early successes in large-scale inter-basin water transfers. Elsewhere in the world, we find much older cases. China's Grand Canal, Roman aqueducts and *quanats*, or sub-surface water galleries from Spain through the entire Middle East down to Baluchistan, are some such cases. Diversion of the Periyar River in 1985 to augment the waters of the Vaigai in Tamil Nadu, the Krishna-Cuddapah (Pennar basin) Canal and the Telegu Ganga Canal that provide water to the Krishna resulting an increase in the drinking water supply to Chennai are some recent cases where IBT has been successful. In the case of the Indira Gandhi Nahar (IGN) or the Rajasthan Canal, each carries over 9.362 km^3 (7.59 million acre feet) of Ravi and Beas waters through the Bhakra for irrigation in the Thar Desert. The Sardar Sarovar Project carries the Narmada waters across seven basins to the arid areas of North Gujarat, Saurashtra and Kutch (Verghese 2003). With the growth of science and engineering and the intensity of water scarcities, IBT projects during the past century have become increasingly large in the volumes handled and bold in their design. Moreover, with water and environment issues increasingly entering the public discourse, planning and executing IBT projects have involved not only considerable engineering and technological experience, but complex social management as well. We illustrate these issues with the help of two examples, one from a rich country context and another from an emerging economy context.

The first is the 50-year old Colorado Big Thomson, USA, which illustrates the life-cycle of a water infrastructure project over a period of rapid socioeconomic change. Relative to the scale of water transfers India is contemplating, the Colorado Big Thomson is a minor intervention, yet it diverts approximately 0.284 km^3 /annum (0.23 million acre-feet) of water from the upper reaches of the western flowing Colorado River, one of the most 'closed' basins in the World, and sends it eastward into the South Platte River basin, which is part of the Mississippi-Missouri basin. This project, implemented by the United States Bureau for Reclamation (USBR), was constructed between 1938 and 1957. Its primary purpose was to provide water for irrigation, and for municipal and industrial use along the front range of the Rocky Mountains in northern Colorado. It provides water to 29 municipalities, including Fort Collins, Boulder, Loveland, and Longmont; over 100 ditch and reservoir companies (water users associations), and 251,000 hectares (620,000 acres) of irrigated land (Colorado State University 2006). The water that flows down the Big Thomson River is also used to generate hydropower, which inter alia drives the pumps that lift the water on the western slopes into the diversion tunnel. In implementing the project, the USBR included the key stakeholders, particularly the irrigation districts (water users associations) which were to benefit from the increased and more reliable water supplies, and the relevant municipalities, all of which collectively formed into the Northern Colorado Water Conservation District (NCWCD). Even when this project was developed, the implementation had to navigate arguments between government agencies, protests from environmentalists concerned with the preservation of a National Park, disputes between the communities in the western and eastern slopes, heated arguments over water rights, and such things as labor and materials shortages brought on by World War II (Autobee 1996). Over the years however, the project has evolved. The NCWCD, effectively the water users, now operates the entire system. Also, growing awareness and new legislation have resulted in increased attention to the environmental needs in both the receiving and 'donating' river systems. Finally, while there remains a vibrant irrigated agricultural economy in the area that utilizes the bulk of the water supply, the relative role of agriculture in the regional economy has significantly diminished, and in the past two decades or so, municipalities, including those further to the south in the urban conurbation of greater Denver, have acquired certain water rights from farmers in order to meet growing domestic and industrial demands. Even today, decades after it was developed, the Colorado Big Thomson project has its detractors. To take a quote from a local newspaper:

> *"New generations take an ample water supply for granted, and political clout has passed to environmental lobbies that have made water providers the goats instead of heroes."* (Hornby 1993).

The second example is the well-known Lesotho Highlands Water Project (LHWP), which, built and managed by Lesotho and South Africa, illustrates the dynamics of IBT in a developing country context. This was developed to divert water from the relatively economically poor, yet water-rich country of Lesotho, to the prosperous but water-short South Africa, specifically to the wealthy province of Gauteng. The project transfers water from the upper reaches of the Orange/Sengu rivers and diverts it into the Vaal River. Initial investigations for this project began in the 1950s, but subsequent attempts to implement it failed as the two countries could not reach an agreement. In the early 1980s, after much deliberation and planning, feasibility studies were undertaken with the involvement of both Lesotho and South Africa, and the project as conceived at that time formed the basis of the treaty between the two governments, which was signed in 1986.

As intended, the LHWP became one of the largest water transfer projects in the world, which was estimated to cost US$8 billion. Phase 1, which was completed in 2004 at a cost of approximately US$2 billion, diverts approximately 750 million m^3 of water per annum. It comprised three storage dams in the upper reaches of the Orange/Sengu river system, 110 km of transfer tunnels leading to the Vaal River via a hydropower station, 300 km of access roads, and, while not included in the original design, a number of environmental and social mitigation and enhancement measures too, have been put in place (Earle and Turton 2005). Royalties and hydropower revenues from Phase 1 contributed approximately US$31 million to Lesotho in 2004, which was about 5% of their GDP.

The location of the major works of the project is sparsely populated. The treaty allowed for the management of the environment, sustaining of existing livelihoods and set up compensation mechanisms for those negatively impacted by the project. The implementation of Phase 1, included environmental impact assessments and environmental action plans, which included resettlement and development, public health and natural environment, and heritage components (Mochebelele 2000). However, a thorough environmental flow analysis was not initiated until 1997, by which time part of the construction activities in phase 1 was already completed (IUCN 2003). The initial concept had been to maximize the quantity of water transferred with limited regard for in-stream flows, but the results from the environmental feasibility assessment (EFA) required that the releases from the already built facilities be increased and design changes be made to Phase 1, at least as much as could be done as the project was already at an advanced state of implementation by the time the results were available (IUCN 2003). The project had assumed that those most affected by its development were the few people located within the inundation pools of the reservoirs, and that there would be little impact on the downstream dwellers. The EFA, however, concluded that there would be significant hydrological, ecological and socioeconomic effects on the people living downstream as well as on the riverine ecosystem. The EFA allowed compensation for these impacted persons, resulting in a doubling of the portion of implementation funds used for environmental-related works from Phase 1 The EFA also contributed to a major re-consideration of the next phases i.e., 2 to 5 of the project (IUCN 2003).

The LHWP however, became infamous for corruption, due to accusations leveled at it and subsequent high profile court cases, some of which are on going. While the presence of corruption is not new in large-scale infrastructure developments and the victims are more often than not, those who are already marginalized, the only positive outcome here is that the offenders have or are being prosecuted, which in turn has improved the overall efficiency and transparency of doing business in Lesotho (Earle and Turton 2005). Earle and Turton (2005) concluded that civil society needs to be equipped and empowered to report corruption; that the authorities need the capacity to investigate; and that the institutional arrangements made should be up to the task at stake, including anti-corruption arrangements such as those that have been established in Lesotho at present. These arrangements included mechanisms to ensure that the contractors entrusted with work have not been involved in any form of corrupt practices in the past.

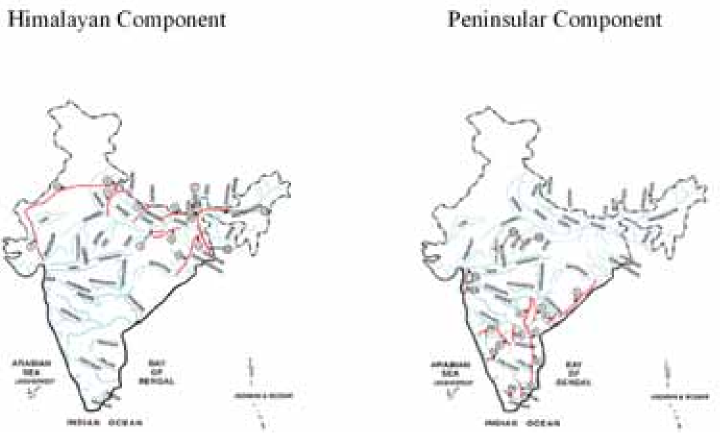
These two examples illustrate that implementing IBTs is a considerable challenge in social and political terms, even in the best of environments. Nevertheless, if planned and executed in a participatory manner that takes into account the suggestions made by various stakeholder groups, sound IBT projects can truly become ‘the lifeblood of developing and extant human settlements’. The major challenge that India’s ILR project faces is how to negotiate with and reconcile the conflicting needs and aspirations of stakeholders to welcome a water enterprise that is of a scale, scope and socio-ecological complexity that the world has never encountered before.

The Indian ILR Project

The project that the Supreme Court and the President have enjoined the Government of India to implement may well be the largest infrastructure project ever undertaken in the world, transferring water from surplus river basins to ease the water shortages in western and southern India, while mitigating the impacts of recurrent floods in eastern India (NWDA 2006). The project will build 30 links and approximately 3,000 storages to connect 37 Himalayan and Peninsular rivers to form a gigantic South Asian water grid. The canals, planned to be 50 to 100 meters wide and more than 6 meters deep, will facilitate the navigation of water. The estimates of key project variables-still in the nature of ‘back-of-the-envelope calculations’—suggest that it will cost a staggering US$123 billion (or Indian Rs. 560,000 crore at 2002 prices), handle 178 km^3 of inter-basin water transfer/per year, build 12,500 km of canals, create 35 giga watts in hydropower capacity, add 35 million hectares to India’s irrigated areas, and generate an unknown volume of navigation and fishery benefits (Mohile 2003; Institution of Engineers 2003; GOI 2003). Approximately 3,700 MW would be required to lift water across major watershed ridges by up to 116 meters. Far from 2016, most observers agree that this project may not be fully complete even by 2050. Verghese (2003), one of its few champions outside the government, suggests it should be viewed as a 50 to 100 year project.

The ILR project is conceptualized in two distinct components: the Himalayan and peninsular (Figure 1). The former will transfer 33 Km^3 of water, and the latter will transfer 141 Km^3 of water through a combined network of 14,900 km long canals (NWDA 2006). The Himalayan Component (HC), with 16 river links, has two sub-components: the first will transfer the surplus waters of the Ganga and Brahmaputra rivers to the Mahanadi Basin and from there the water will be relayed to Godavari, Godavari to Krishna, Krishna to Pennar and Pennar to the Cauvery basins. The second sub-component will transfer water from the eastern Ganga tributaries to benefit the western parts of the Ganga and the Sabarmati river basins. Altogether, these transfers will mitigate floods in the eastern parts of the Ganga Basin, and provide the western parts of the basin with irrigation and water supplies. The Himalayan component needs several large dams in Bhutan and Nepal to store and transfer flood waters from the tributaries of the Ganga and Brahmaputra rivers, and also within India to transfer the surplus waters of

Figure 1. Himalayan and peninsular component of the ILR project.



Himalayan Component

Peninsular Component

Source: NWDA (2006)

the Mahanadi and Godavari rivers. The peninsular component has 16 major canals and four sub-components: 1) linking the Mahanadi-Godavari-Krishna-Cauvery-Vaigai rivers; 2) linking west flowing rivers that are south of Tapi and north of Bombay; 3) linking the Ken-Betwa and Parbati-Kalisindh-Chambal rivers; and 4) diverting the flow in some of the west flowing rivers to the eastern side. The en route irrigation under the peninsular component is expected to irrigate a substantial area as proposed under the NRLP. This area to be irrigated is situated in arid and semi-arid western and peninsular India. The total cost of the project includes three components: 1) the peninsular component will cost US$23 billion (Rs.1, 06,000 crore); 2) the Himalayan component will cost US$ 41 billon (Rs.1, 85,000 crore); and 3) the hydroelectric component will cost US$59 billion (Rs. 2, 69,000 crore). The quantity of water diverted in the peninsular component will be 141 cubic kilometers and in the Himalayan component it will be 33 cubic kilometers. The total power generated via the hydroelectric component will be 34 gega watts (GW) – 4 GW in the peninsular component and 30 GW in the Himalayan component (Rath 2003).

What makes ILR unique is its unrivalled grandiosity. If and when completed, ILR will handle four times more water than China’s South to North water transfer project, which is one of the largest inter-basin water transfer projects implemented in the world at present (Stone and Jia 2006). ILR will handle four times more water than the Three Gorges Dam; five times all inter-basin water transfers completed in the U.S.A; and more than six times the total transfer of the six inter-basin water transfers projects already operational in India namely, Sharda-Sahayak; Beas-Sutlej; Madhopur-Beas Link; Kurnool Cudappa Cana; Periya Vegai Link; and Telgu Ganga. The ILR cost, as presently ‘guesstimated’, would be three times the cost of China’s South-North water transfers scheme; six times the cost of Three Gorges Project, and twenty times the estimated costs of the Red-Dead connection in the Middle East. ILR will require a larger investment than the sum total of all irrigation investments made by the governments of colonial and free India since 1830. And this cost is based on numbers that are little more than a conservative ‘guesstimate’ that more than likely excludes the cost of land acquisition. When the cost of land acquisition and rehabilitation and resettlement, besides the endemic cost and the inevitable time overruns, are factored in, ILR will most likely cost several times more than the present US$123 billion estimate.

Only nine of the 30 proposed links are independent, and can be executed without working on other links. In the first stage of this mammoth project, which won government approval last August, a 230-kilometer canal will be dug to divert water from the Ken River to the Betwa River in the northern Madhya Pradesh Province. A dam and small hydroelectric plant will be built in the Panna Tiger Reserve. Work on this US$1.1 billion costing first component of the NRL project is underway and is scheduled to be completed in 8 years (Bagla 2006).

Justification of ILR

The most significant question being raised about ILR by critics is its justification. The *raison d'etre* of the project is the accentuating water scarcity in western and peninsular India. The low per capita availability of utilizable water, high spatial and temporal variability of rainfall and the associated droughts and floods are other major factors. By 2050, the per capita water availability in India is expected to fall from the present 1,820 m^3 to 1,140 m^3, far less than the water scarcity thresholds of 1,700 m^3/person/year defined by Falkenmark et al. (1994) as necessary for civilized living. Spatial inequality too is extreme: the Ganga-Brahmaputra-Meghna basins, which cover one third of the country's total land area, are home to 44 % of India's population, but drain more than 60 % of the country's water resources.[2] In contrast, the Krishna, Cauvery and, Penner river basins and the eastward flowing rivers between Penner and Kanyakumari cover 16 % of the total land area, host 17 % of the population, but drain only 6 % of India's water resources (Amarasinghe et al. 2005). In India's 19 major river basins, only 55 % of the total water resources are utilizable. As a result, more than 220 million people have a per capita water supply that is below 1,000 m^3/ per year, indicating the emergence of severe regional water scarcities according to Falkenmark et al. (1994).

Owing to these unequal endowments, India's river basins are at different degrees of 'closure'. The Indus Basin withdraws more than 1,600 m^3 per person/year, whereas the Brahmaputra Basin withdraws only 290 m^3 per person/year. The Indus, Penner, Tapi, Sabarmati — the west flowing rivers in the Kutch, Saurashtra and Rajasthan (Luni) regions, and the east flowing rivers between Pennar and Kanyakumari suffer over-development (Amarasinghe et al. 2005) and are physically water-scarce (IWMI 2000). The needs of these areas can be addressed, it is argued, by augmenting their natural flows through the transfer of surplus waters from the Himalayan rivers.

It is argued that diverting a portion of the surplus flood waters from the Himalayan rivers into the drought-prone areas can only be a win-win proposition. Annual floods, on average, affect more than 7 million ha of the total land area, 3 million ha of the cropped area and 34 million people, mostly in the eastern parts, and inflicts an annual damage of well over US$220

---

[2] The Brahmaputra subbasin alone, with only 6 % of the land area and 4 % of the population, drains 31 % of the total water resources. And due to geographical restrictions, only 4 % of the Brahmaputra Basin's vast water resources are potentially utilizable within the basin.

million (Rs.1,000 crores) (GOI 1998). In contrast, recurrent droughts affect 19 % of the country, 68 % of the cropped area and 12 % of the population (Nair and Radhakrishna 2005).The reservoir storages and the canal diversions in ILR are expected to reduce flood damages by 35 % (Sinha et al. 2005) and ease drought-proneness in semi-arid and arid parts, besides making 12 km^3 of water available for domestic and industrial water supplies in these drought-prone districts.

India is also blamed for having neglected storage creation, resulting in *economic* water scarcity that may impede its economic growth. Other arid and semi-arid regions of the world have invested heavily in storage creation; the U.S.A has a per capita storage capacity of 5,961 m^3; Australia has 4,717 m^3, and Brazil has 3,388 m^3. Even China has increased its per capita storage capacity to 2,486 m^3 while India's per capita storage capacity is a puny 200 m^3/person at present and declining with increasing population. It is imperative that India increases its storage for regulating the vast amount of runoff that otherwise cannot be beneficially utilized. The NRLP water transfers of 178 km^3 will increase utilizable surface water resources by 25 % and improve water accessibility in water-scarce regions.

As a concept, the ILR has been doing the rounds for over a century; however, as a serious proposition, it has "not been recommended by anyone" (Iyer 2003). Even the National Commission on Integrated Water Resources Development (NCIWRD), which considered the proposal in great detail, was lukewarm towards its implementation, and actually suggested caution in considering the project as a solution to water-distribution problems. Who then are the proponents of the ILR Project? This is a difficult question because besides a small group of large-scale irrigation proponents, the Supreme Court and the President of India, the votaries for the NRLP are far less vocal than the growing lobby of antagonists of the project.

The NCIWRD report, which is widely viewed in lay circles as the first cut justification of the NRLP idea, emphasized self-sufficiency in food production and improved rural livelihoods as two key justifications for the ILR project. Assuming the criticality of maintaining national food self-sufficiency and agricultural exports, the Commission projected a grain demand in the range of 425 to 494 million tonnes for India by 2050 and argued for the need to increase the country's irrigation potential to 160 million ha, which is 20 million more than what can be achieved without basin transfers. Thus, it is stated "….one of the most effective ways to increase the irrigation potential for increasing food grain production, mitigate(ing) floods and droughts and reduce(ing) regional imbalances in the availability of water, is the interlinking of rivers to transfer water from the surplus rivers to deficit areas..." (NWDA 2006). The surface irrigation of the river linking project alone expects to add 25 million ha of irrigated land. However, the NCIWRD commission was not unanimous in its support for river linking; some of the members issued a dissenting view that is included in the report itself.

Improving rural livelihoods is advanced as another justification for the ILR project. The rural population in India is projected to peak at about 775 million by 2015 (UN 2004). The commission projects that the rural population will decrease to about 610 million by 2050, which will be similar to the rural population levels in 1988. The agriculturally active population estimated in 1988 was 488 million (FAO 2006). With the present level of economic growth however, one would expect that the population whose livelihood depend solely on agriculture to be inevitably much lower than today's level (548 million in 2001). Thus it is not clear how total agriculturally dependent livelihoods in the future can be a justification for the NRLP irrigation transfers.

None of the critics undermine the seriousness of the specter of water scarcity in western and peninsular India. But, according to them, just because the Brahmaputra, which accounts for the bulk of India’s water resources, flows rather inconveniently in a remote corner of the country, does not constitute a good enough reason for a canal and dam building spree on the scale proposed. Critics argue that there are other solutions besides ILR, which have not been properly considered. A strong and strident army of ‘water-warriors’ argue that if the precipitation within the watersheds or subbasins is harvested and conserved properly, meeting domestic water needs will not be a problem in most parts of the country. They also argue that dams waste more water than meet the requisite water needs. While the whole country needed about 30 km^3 of water for meeting annual domestic needs in 1997-1998, India experienced a loss of 36 km^3 in that year alone through evaporation from the reservoirs.

Some critics point to desalination as a viable component in creating an alternative to the NRL project, especially as desalination is no longer considered prohibitively expensive. The capacity for desalinating water has increased globally from 1.5 million m^3 per day to the current figure of more than 20 million m^3 per day. This has reduced the cost-price of desalinated water to less than US$1.00/$m^3$ for seawater and less than US$0.50/$m^3$ for brackish water (Bandyopadhyaya and Praveen 2003). Arid countries such as Saudi Arabia already depend heavily on desalination for meeting a substantial part of their non-irrigation water demand. Closer to home, companies are now ready to market drinking water at a price of 5 paise per liter. The emerging technology of rapid spray evaporation (RSE) is likely to cut costs further. However, with the recent escalation in energy costs, desalination also needs to be looked at with a more critical eye.

Water demand management in agriculture offers enormous scope that remains untapped for meeting future water demand. According to Bandyopadhyaya and Praveen (2003), “Irrigation is no longer ‘watering the land’ but supplying water for growth of crops…”; and Iyer (2003) argues that “the answer to the sharing problem in the Cauvery lies in both Tamil Nadu and Karnataka learning to reduce their excessive demands on the waters of the river through a combination of measures; the ‘shortage’ will then disappear.”

Emerging Critique of the ILR Proposal

ILR has generated a highly polarized debate on its pros and cons, with its supporters—a small band—coming largely from government advocates of large-scale irrigation and the political class, and a much larger, vocal and strident group of critics and opponents from civil society and academia. In a single issue of *Himal*, a South Asian journal, Verghese (2003) found ILR described in a variety of ways such as ‘frighteningly grandiose’, a ‘misapplied vision’, ‘extravagantly stupid’ ‘annihilatingly wrong’, a case of putting the ‘cart before the horse’, a ‘sub-continental fiasco’, ‘a flood of nonsense’, a ‘dangerous delusion’ or a case of ‘hydro-hubris’. According to Iyer (2003), “It amounts to nothing less than the redrawing of the geography of the country.” According to Bandyopadhyaya and Praveen (2003), the proposal claims to package an uncertain and questionable idea as a desirable one. Some of the major criticisms of the project are about its socioeconomic viability, environmental impacts, displacement and rehabilitation of affected people, the challenge of resource mobilization, geo-political constraints as well as domestic political dynamics.

Benefits and Costs

The ILR project envisages many benefits. It expects to: add 34,000 MW of hydropower to the national grid of which 3,500 MW would be used in various lifts; supply much needed drinking water to several millions of people and industrial water supplies to drought-prone and water-scarce cities in the west and south; mitigate floods in the east and droughts in the west and the south. The large canals linking the rivers are also expected to facilitate inland navigation. Increased irrigation—25 million ha through surface irrigation and 10 million ha through groundwater irrigation—in water-scarce western and peninsular regions is the top benefit envisaged from the ILR project. This is expected to generate more employment and boost crop output and farm incomes, and provide multiplier benefits through backward linkages such as farm equipment and input supplies and forward linkages such as agro-processing industries.

This key plank of the project has come under scathing criticism. The most eloquent has been from Rath (2003). Based on simple, back of the envelope calculations, Rath shows that assuming a 7 % interest rate per year, the annual capital costs and interest to recover the total capital over a period 50 years will be US$110/ha (or Rs.2,015/acre) in the peninsular component and Rs.15,030/acre in the Himalayan component. For irrigating hybrid *jawar* (sorghum) in peninsular India, he shows that the required annual capital recovery cost alone will be US$221/ha (Rs. 4,131/acre). Similarly, the annual capital recovery cost at 7 % interest over 50 years amounts to US$0.30 (Rs.13.3) per watt of hydropower. If we assume a 7 % interest rate to be charged on the capital during the construction period, the total cost of the three components will amount to US$252 billion (Rs.11,47,873 crore), approximately double of what is now suggested. On the further assumption of a 5 % annual rate of inflation, the project will commit India to a project outlay of US$22 billion (Rs.100,000 crore) per year.

Environmental Concerns

Environmentalists are worried about the ecological impacts of the project of such a massive scale. In May 2003, the Government of India's own Ministry of Environment and Forests raised 23 environmental concerns about ILR. Independent researchers too worry on many counts. Some have pointed to the dangers of the seismic hazard, especially in the Himalayan component (Bandyopadhyaya and Praveen 2003), and many worry about the transfer of river pollution that accompanies inter-basin water transfers. The loss of forests and biodiversity, of course, are recurring themes. Many others have questioned the subjective concept of the availability of 'surplus' flows in some river basins that lie at the heart of inter-basin transfers. An extreme view, according to Bandyopadhyaya and Praveen (2003), is "…from a holistic perspective, one does not see any 'surplus' water, because every drop performs some ecological service all the time. The ecosystems evolve by making optimal use of all the water available. If a decision is taken to move some amount of water away from a basin, a proportional damage will be done to the ecosystem, depending on the service provided by that amount of water…there is no 'free surplus' water in a basin that can be taken away without a price." Proponents of this view argue that the water flowing into the sea is not waste, but rather a crucial link in the water cycle. With the link broken, the ecological balance of land and oceans, fresh water and sea water, is also disrupted (Shiva 2003). But others argue differently. They opine that some Indian river basins have vast non-utilizable water resources, even after meeting all human and eco-system services needs. The

Brahmaputra River basin’s renewable water resource capacity is about 584 km^3, which is about a quarter of India’s total water resources. And only about a quarter of that is potentially utilizable within the basin. Water accounting of a few other basins also show significant non-utilizable water resources. A part of this non-utilizable water resource can be beneficially used for the rapidly expanding population, without a noticeable impact on the eco-systems.

The recent groundswell of worldwide opposition to large dams and irrigation projects that interfere with nature in a drastic manner has found a window of expression in the debates on ILR. Shiva (2003) considers ILR to be an act of violence against nature: “Violence is not intrinsic to the use of river waters for human needs. It is a particular characteristic of gigantic river valley projects that work *against*, and not *with*, the logic of the river. These projects are based on reductionist assumptions, which relate water use not to nature’s processes but to the processes of revenue and profit generation…Rivers, instead of being seen as sources of life, become sources of cash. In Worster’s words, the river ends up becoming an assembly line, rolling increasingly toward the goal of unlimited production. The irrigated factory drinks the region dry.” Iyer (2003) is acerbic in his comments on IRL projects: “Are rivers bundles of pipelines to be cut, turned around, welded and re-joined? This is technological hubris – arrogance – of the worst description, prometheanism of the crassest kind. The country needs to be saved from this madness.”

Yet more recently the pendulum has begun to swing back towards investments in water infrastructure, and in some countries, most notably in China, which did not have to depend on external sources to secure the necessary financing, there have been many dams constructed in the recent past. The ICOLD World Register of dams shows that China has 4,434 dams (ICOLD 2000). Other sources estimate much higher figures for dam construction in China, as high as 22,000 large dams (WCD 2000). At WSSD in Johannesburg, recognition was given to hydropower as a renewable resource for power generation, and the World Bank water strategy (World Bank 2005) laid the groundwork for a re-engagement of the multi-lateral banks in large-scale water infrastructure. Most recently the Comprehensive Assessment of Food and Agriculture (CA 2006) determined that investments in large-scale infrastructure will be necessary in regions where there has historically been under-investment, such as sub-Saharan Africa and parts of Asia. That Assessment said, investment in large-scale irrigation, even as a component of multi-purpose developments is generally economically unattractive. Also, while certain parties may again be attracted to investing in water infrastructure, the modalities to ensure that the infrastructure developed is effective and sustainable remain highly contentious.

Social Costs

ILR is likely to cause the displacement of tribesmen and poor people on a massive scale; and India’s past record in fair and just rehabilitation of ‘Project-affected people’ does not inspire confidence among ILR critics that the project will not ride roughshod over millions of displaced people. The construction of reservoirs and river-linking canals in the peninsular component alone expects to displace more than 583,000 people and submerge large areas of forest, agriculture and non-agricultural land. Two of the proposed reservoirs, Inchampalli at Inchampalli-Nagarjunasagar and the Polavaram at Godavari Polavaram –Krishna (Vijayawada) and the associated river-linking canals are estimated to displace more than 100 thousand people in each locality.

According to one estimate, the network of canals, extending to about 10,500 kms, alone would displace about 5.5 million tribesmen and farmers (Vombatkere 2003). To this number, we must add the people to be displaced by the various reservoirs planned. The plight of these people becomes even more serious because the government of India does not have a sound and clearly spelt out resettlement and rehabilitation policy (Bandyopadhyaya and Praveen 2003).

A major lesson to be drawn from the recent history of large-scale water resources projects in India and elsewhere is that despite government policies and procedures that include the necessary redress measures, displaced populations still suffer unduly. Although assurances are given to mitigate the social impacts of such projects, it has proven to be difficult to transfer such assurances to deeds. However, it must be said that this is not something insurmountable.

Although many often focus on the social impacts of displacement of persons under IBTs, these multi-purpose water transfers do bring significant social benefits too. Many water transfer projects require both skilled and unskilled labor, and the training provided for the local and sometimes for the regional or national workforce, is a major advantage for future endeavors. Often, large water development projects increase access to new infrastructure: roads, which otherwise takes hours to reach to a decent mode of transport; markets, which otherwise are not even reachable for several days; clean water supply- without which people, especially women and children, trek hours to find a potable water source. The large irrigation projects not only enhance the livelihood of the farming families in the command area, but also bring substantial multiplier effects to the region, and in some cases at the national level too (WCD 2000). The Bhakra Irrigation Project’s regional multiplier is 1.7 of the direct benefits (Bhatia and Malik 2005). And the Indus Basin, where irrigation is an integral part of the crop production system, meets more than 80 % of the food production deficits of other basins in India. It is not a secret that irrigation was a major factor in transforming the major food deficits in India in the 1950s and 1960s to present day food surpluses.

Resources Mobilization

Rath (2003) called the ILR a ‘pie in the sky’ because he, like many others, is skeptical of the government’s capacity to mobilize the kind of investable funds that ILR demands. Budgetary provisions made so far for water development are far from enough to complete ongoing projects. During recent years, under a special ‘Accelerated Irrigation Benefits Scheme’, the government has been setting aside funds for the so-called ‘last mile’ projects (projects which are nearly complete but have been languishing for years for the lack of relatively modest funds to complete minor residual work). Many incomplete projects dot the country, to the extent that the NCIWRD estimated that India needs Rs.70,000 crores during the Tenth Plan and Rs.110,000 crores during the Eleventh Plan just to complete these ‘last mile’ projects. Senior researchers like Iyer (2003) quip, “We have had great difficulty in completing even single projects successfully and we want to embark on thirty massive projects at the same time.”

Domestic Politics

Domestic and regional geo-politics play a key role in the discussions on ILR. For one, for the Indian political class, ILR has provided a vehicle for grandstanding. As Iyer (2003) suggests, “Gigantism always casts an irresistible spell on our bureaucracy and technocracy as well as on our politicians.” What are now recognized as the Supreme Court’s unpremeditated casual remarks, were zealously adopted by senior NDA government leaders as the court’s order by the government ‘with uncharacteristic promptitude and enthusiasm’. The successor UPA government is procrastinating on the project; however, there is little doubt that political push at a sufficiently high level will be enough for the technocracy to brush aside all the debates and launch the country headlong into ILR implementation quite like Lin Piao, China’s Premier launched his country in the South-to-North water transfer project in 1995. Such a rushed scenario at best would result in developments that are less than economically, socially and environmentally optimum for India’s future, and, more than likely, would fail to deliver on the promised water-secure future.

But politics may also act as a barrier to ILR. Even within India, creating a strong political consensus around the project will require considerable effort. Neither political negotiations nor arm-twisting of the kind Mrs. Indira Gandhi used to settle water disputes among states promise such consensus; economics may help wrench open a window to cooperation. Bihar refused to let Ganga waters to be transferred, arguing that if her farmers are unable to use her water today, does not mean they will remain unable to do so forever. Her leader Lalu Prasad Yadav, however, did a volte-face when someone mentioned Bihar might get paid for the Ganga water she allows to be transferred.

Even more serious political issues arise when the dynamics in riparian countries—Nepal, Bangladesh, Bhutan—are considered. The realization of the Himalayan component is critically dependent on the agreement of neighboring countries Nepal and Bhutan to the proposed construction, especially of dams, in their respective territories. Bangladesh, as a downstream country, will be an affected party, and needs to be taken into consideration. Under the India-Bangladesh Treaty of December 1996 on the sharing of Ganga waters, India has undertaken to protect the flows arriving at Farakka, which is the sharing point. West Bengal has only reluctantly agreed to the large allocations of waters to Bangladesh under the Ganga Treaty and has been pressing the needs of Calcutta Port. On the other hand, Bangladesh may feel threatened that a diversion of waters from the Ganga to the southern rivers will not be consistent with the sharing arrangement under the Treaty.

Owing to this geo-political conundrum, the planning of the Himalayan component of IRL as well as discussions about it are shrouded in opacity. Even as a National Commission, the National Commission of Integrated Water Resources Development Project (NCIWRDP) could not have access to data related to the Himalayan component (NCIWRD, 1999:187). This opaque data environment obfuscates several critical issues. For instance, how can one estimate the minimum flows in Padma or Meghna or the Hooghly-Bhagirathi required for sustaining fishing livelihoods in southern Bangladesh and the state of West Bengal. Or as Bandyopadhyaya and Praveen (2003) ask: “What will be the impact of the diversion of the 10 % of the lean season flow from ‘surplus’ river basins on the groundwater resources and saline incursion in the downstream areas?”

Protagonists of ILR, like Verghese and Prabhu are the first to accept that ILR as a concept is a non-starter until India offers its co-riparian countries a deal they cannot refuse. Verghese (2003) suggests that the project can be a win-win opportunity for all neighbors. However, civil society players in Nepal and Bangladesh do not share Verghese’s positive view, at least not yet.

Questioning Core Assumptions

It would be wrong to say that the arguments for and against ILR are evenly balanced. Even the available sketchy arguments based on superficial information and an analytic base raise serious questions about: a) what is ILR b) what precisely are the problems that ILR would help resolve c) is ILR the best available alternative for resolving those issues d) are the problems ILR is currently designed to resolve likely to stay that way when the project is commissioned 50 - 70 years hence?

Recent work by IWMI and partner researchers throws new light on these questions. Many of the factors that the NCIWRD projections were based on have already undergone significant changes, and could alter future water supply and demand projections. For instance, the justification for, as well as the cost-benefit calculus of the ILR in its broadest conception, critically hinges upon projections of population growth, urbanization patterns, and occupational diversification. And contrary to NCIWRD prognoses, recent data suggests that all of the said factors are displaying significant rates of change. In contrast to the NCIWRD projected state-wise population growth by pro-rata distribution of national population projections from the 1991 population census, the new regional population growth projections, incorporating age-size structure, HIV/AIDS and adjusted fertility and mortality estimates from the 2001 census, show vastly different emerging patterns (Mahmood et al 2006). According to these new estimates, India's population is projected to increase from 1,027 million in 2001 to 1,190 million by 2051 and stabilize thereafter. Although the total population is not drastically different to the NCIWRD projections, many states, especially those which are water-scarce, have significantly different growth patterns. Andhra Pradesh, Kerala, Karnataka, Punjab, and Tami Nadu are expected to face appreciably declining population trends before 2050. Haryana, Gujarat, Maharashtra, Orissa and the West Bengal too will experience a moderate decline, while Bihar, Jharkhand, Madya Pradesh, and Chattis Garh are expected to show an increase in population. These are the states where pressure on farmlands and demand for irrigation will continue to be high. This new regional demographic calculus needs to be incorporated into future water demand estimations, although even at this stage the differences between these estimates and those used in the overall conception of the NRL project underscore the need to revisit the basic idea of the scope and ultimate effectiveness of ILR.

NCIWRD's prognosis of food demand too has received considerable scrutiny from proponents and opponents of the ILR debate. The food grain demand projection (279 kg/person and 450 million MT/year total by 2050) of the Commission was a major driver for irrigation demand estimation. At this rate of food grain consumption, the total calorie intake per person is estimated to be at least 4,000 kcal/day (assuming that grains constitute 63 % of the total calorie supply). These estimates are way above the average calorie intake of even the most developed economies at present, and are clearly out of line with the changing consumption patterns. A recent study (Amarasinghe et al. 2006) incorporating a number of significant aspects from the changing consumption patterns over the past decade and their consequences for the future, projects India's total grain demand to increase from 209 million MT in 2000 to about 380 million MT by 2050. This projection includes 120 million MT of feed grain demand, which is a 10-fold increase from the present levels and a factor that was not considered in the earlier estimates. Even the results of this study, however, fall short of the NCIWRD's projection of total grain demand by 114 million MT.

It is argued by many that to heighten the need for expanding irrigation, the NCIWRD took an unduly bleak view of the potential to increase food grain yields. They assumed average grain yield to fall from 1.5 tonnes/ha in 1993 to 3.1 tonnes/ha in 2050 (2.3 and 1.0 tons/ha on irrigated and rain-fed yields respectively in 1993 to 4.0 and 1.5 tons/ha on these by 2050). Critics argue that 50 years is a long period and India can easily outdo the Commission’s unrealistically low projections of yield growth with far cheaper and simpler interventions than ILR. China and India had similar grain yields in the early 1960s, but China’s present yield is two and a half times more that that of India. Over the same period, the USA’s grain yield increased by almost 4 tonnes from 2.5 tonnes/ha in 1961. Can’t India’s average yield be increased to 4.0 tonnes/ha, China’s present level, even over a 50-year period? If yes, India will be self-sufficient in food without *any* additional land for grains.

NCIWRD’s prognosis for how India’s future of irrigation shapes up is also a contentious issue. According to the Commission, surface water supply would be the dominant form of irrigation by 2050. The Commission projects that surface and groundwater irrigated area will change from 1993’s levels of 55% and 45% of the gross irrigated area to 45% and 55%, respectively, by 2050. However, the developments over the last two decades show a completely opposite trend. There was no appreciable increase in surface irrigated area, although due largely to private small-scale investments, the groundwater irrigated area recorded a rapid growth. Today, groundwater contributes to 33 million ha which constitutes 63 % of the net irrigated area and 64 % of the gross irrigated area. It is therefore, largely due to this increase in groundwater irrigation that the gross irrigated area projection of 79 million ha for the year 2010 has been already achieved by the year 2000. But the consistency of these numbers depends on how far groundwater irrigation can grow without any surface irrigation growth?

Many contend that groundwater irrigation cannot be increased without surface irrigation recharge. But a substantial part of growth in groundwater irrigated areas in the last decade took place in districts outside the command areas (Shah et al. 2003) and showed no significant spatial dependence on surface irrigated area growth (Bhaduri et al. 2006). Our analysis shows that if the 10 million ha of net surface irrigated area from the projects under construction and another 25 to 35 million ha of net groundwater irrigated area is added to the present level of irrigation, the gross irrigated area will increase to about 130 to 140 million ha. This is the area required for achieving the Commission’s projections of, and perhaps the bloated, self-sufficiency targets of grains. With this increase, groundwater (GW) irrigation by 2050 will cover more than 70 % of the gross irrigated area. Such a change will significantly reduce the total irrigation demand due to differences of efficiencies between surface irrigation (60%) and GW irrigation (77%). But, can the commission’s optimistic assumptions on irrigation efficiency increase be realized by 2050?

The commission assumed a significant increase in irrigation efficiencies—from 35%-40% to 60% for surface irrigation and from 65%-70% to 75% for groundwater irrigation across all the river basins. The little information we have today on the variation of irrigation efficiency across river basins is not adequate to predict future directions. However, they show that groundwater irrigation efficiency is already close to or even higher than the commission’s projections (Kumar et al. 2006). But the surface irrigation efficiency has shown virtually no increase over the last decade. With water-scarce river basins approaching high degrees of closure, there are no flows to the sea on many days of the year. In these, efficiencies of surface irrigation are low, but they have high basin efficiency due to reuse of the return flows of irrigation Thus increasing irrigation efficiency in one location, and then using the saved water for new locations or for other purposes, would certainly affect some other water users elsewhere. We need to know more on the interactions of efficiencies at the system and basin levels before making firm statements on the potential improvement of efficiency in the surface systems. Or, at least we need conservative assumptions on the potential increases based on the information currently available.

To what extent will the younger generation of today take to agriculture as their primary occupation in the future? NCIWRD assumed that many rural people would stay in agriculture and the access to irrigation is necessary for adequate livelihoods for them. However, according to recent research on the agriculture demography of India (Amrita et al. 2006), today's younger generation perceived it differently. There is a high likelihood that today's young rural farmers will move out of agriculture, or at least keep it as a secondary income activity, regardless of the increased access to irrigation. This is more evident in the group who has different skills and better education. The tendency of moving out of agriculture is higher where the distance to travel to town or urban centers is less. Certainly, future generations of India will be more educated, and will be acquainted with better skills. And many rural centers are being transformed to small towns and towns to sprawling urban centers. Infrastructure facilities such as access to roads, electricity, and telecommunication are also increasing. Thus, the migration from permanent rural agriculture to other primary income generating activities will increase. So we also need a better understanding of the emerging trends of the agriculture demography and the resulting land use patterns to project the future agriculture water demand.

Did the commission's report overlook the potential of rain-fed agriculture? They projected only a modest growth from 1.0 tons/ha in 1993 to 1.5 tons/ha by 2050. At present, rain-fed area accounted for 56 % of the grain crop but contributed to only 39 % of the total production. If the rain-fed yield can be doubled over the next 50 years, the grain production on the existing rain-fed lands can alone be increased by 81 million metric tonnes. This kind of increase in grain production will meet a substantial part of the future food demand. IWMI research shows that supplemental irrigation, especially during the water-stress period of the reproductive stage of crop growth, can benefit a substantial part of the rain-fed area (Sharma et al. 2006). And this requires collecting only 18-20 km^3/year of water through rainwater harvesting using small-scale structures. They argue, that water harvesting of this magnitude would have no effect on the downstream users.

The commission's eco-system water demand estimate is an anathema to environmentalists and a concern to many others too. And, perhaps, they have every reason to be critical. Even the commission has admitted that the eco-system water demand estimate— 20 km^3 - 1 %— median of the mean annual runoff of all river basins is not an adequate figure. Preliminary research by IWMI on environmental water demand shows that in many basins, depending on their hydrological variability, a healthy river ecosystem may be maintained even with 10-20 % of the environmental flow allocations from the average annual runoff (Smahktin et al. 2006). Many argue that environmental water demand should include the needs of wetlands, for cleaning the polluted rivers, for fisheries' needs in the down streams etc. All these, and the resulting ecosystem water needs will have a significant impact on inter-basin water transfers, as the ultimate decision of the surplus or the level of closure of river basins is decided on what part of the utilizable water resources are required for the eco-system water needs.

Concluding Remarks

If the fate of ILR were decided on the shape of the present national debate around it, the dice are heavily loaded against it. However, this intensely polarized ongoing Indian debate about ILR is a product of a plurality of prevailing conditions and past experiences. A classic example is the turn the debate takes over different years: in a year of widespread monsoon failure and hydrological drought, when concerns of water scarcity dominate media attention and public debate, demand for state intervention through grandiose schemes like the ILR gathers momentum. In contrast, in years of nation-wide good monsoon—such as 2005 and 2006—water infrastructure issues fade from public spaces.

It is possible to argue that the present proposal for ILR has come a decade too soon. Many factors may change, which are likely to create conditions favorable for a comprehensive solution of the kind the ILR’s proponents promise, although it is likely to be quite different in nature to the ILR that is presently conceived. In particular, the following seven contingencies may be important in determining how the country will plan its water infrastructure investments over the coming decade or two:

Economic Growth

Many bold infrastructure investment proposals appear financially unfeasible in a low-income economy with limited capacity to generate investible resources. It is no accident that over 90 % of the IBT projects that Snaddon, Davis and Wishart (1999) review are from the US, Australia, New Zealand, Europe or other rich economies. Mao proposed China’s South-to-North water transfer project in the early 1950s; however, it was the government of only a much richer China in the mid-1990s that began putting their money on an idea that Mao had mooted. The ILR proposal of investing US$120 billion sounds outrageously bold for an Indian economy of US$700 billion; however, if the Indian economy keeps growing at 8-9 %/year, the proposal may not appear outlandish in a decade or so, especially if its proponents can produce a convincing justification for it;

Improved Public Systems

Implicit in much civil society opposition to ILR is the abysmal track record of water bureaucracies to deliver on their promises. Even though India has a very low storage per capita, it is ironic that most of its dams seldom fill up to the full, canals never reach designed command areas; public irrigation systems cost many times more per hectare to build than they ought to; and hydroelectric plants seldom perform at par. This chronic underperformance median —caused in part by poor capacity and in part by lack of accountability mechanisms—has created a confidence crisis in public systems. However, with creeping improvement in other infrastructure sectors—notably, roads, railways and power—new institutional models for infrastructure creation and management are likely to restore the country’s confidence in its capacity to create and manage large infrastructure projects.

Rehabilitation

By the same token, the question of managing displacement and rehabilitation of project-affected people in water infrastructure projects will increasingly get benchmarked against road, SEZ and other high-stake infrastructure projects where economic costs of delays or inaction are far higher than irrigation projects. Unless the country puts into place a more humane and widely acceptable rehabilitation policy, infrastructure projects in economically more dynamic sectors are likely to run into road blocks. Much better rehabilitation packages recently offered by some private sector players, such as Reliance and Tata, is an indication of movement in this direction.

Economic Water Scarcity

What responses India forges to respond to water scarcity will depend critically on the revenue model that it can implement to make water infrastructure viable in economic terms. The litmus test for scarcity of anything is its increased price. Ironically, growing water scarcity in India's countryside and towns is still producing only weak and fragmented price signals, especially for the water services delivered by public systems. This raises big questions about how a huge infrastructure investment that a project like ILR implies, would be financed and sustained. Financing its construction and O & M wholly through taxes would be hard to sell, especially if the revenue generation model cannot even take care of maintenance and repair, as has been the case with much public irrigation infrastructure. Arguably, the ability as well as willingness to pay for better water service is linked to disposable incomes in domestic uses and water productivity in irrigation. With economic growth, as the 'median voter' with higher disposable income demands better water services and is willing to pay for them, large-scale investments in water infrastructure will become more viable in financial terms. Economic water scarcity—in terms of willingness to pay for scarce water—will also affect the political dynamics of water sharing. So far, water-scarce states are increasing their share in national water resources using adjudication or central government's authority. However, as water-scarce states get richer, they will be willing to pay water-rich poor states for water imports just as Gauteng paid Lesotho and Singapore paid Malaysia.

Agricultural Diversification

In purely economic terms, public investments in irrigation can hardly be justified in today's India. At the aggregate level, the difference in gross value of output on an irrigated and unirrigated hectare is just about US$100-120/year while it costs US$3,500-4,000 to bring an additional hectare under public irrigation. This is because most command areas are used to grow food grains, while high-value crops are grown outside the command areas. In California, Spain, and Victoria in Australia, irrigation supports a gross value of farm output in the amount of US$5,000-9,000/ha, as irrigated land is generally used for high-value export crops. Movement in this direction—of using reliable irrigation for growing high-value crops for urban markets and exports—is gathering momentum in many parts of India. Farmers using irrigation for value-added farming, demand a better and more reliable irrigation service, and are willing to pay for it. Should such a trend gather momentum, farmers in water-scarce western and southern India will make a stronger economic and political demand for ILR type interventions.

Rising Energy Costs

Irrigation expansion in India—South Asia in general—during the recent decades has come not from public investments in surface irrigation projects but from private investments in small lift irrigation systems, using mostly ground but also surface water sources. These offer the advantage of flexible, reliable, on-time irrigation that most surface sources are unable to provide. However, this mode of irrigation development is highly energy intensive; and as energy prices—electricity and diesel—rise relative to farm product prices, one should expect a growing preference from farmers either for superior irrigation from surface water sources or supply of surface water for groundwater recharge. Rising relative energy prices may have a dramatic impact on rural India's support for an investment proposal such as the ILR.

Urbanization

Most Indian towns and cities depend largely on groundwater for running their water supply systems. Experience around the world shows that as a village grows into a town and thence into a city, its area extent grows at a much slower pace than its population. And when the population density of a settlement rises, its groundwater fails to keep pace with water demand regardless of water harvesting and recharge. Beyond a stage, a city invariably has to source its water from a distant reservoir. This is becoming increasingly evident in India, but more so in China whose urban water supply trends present a leading indicator to India. Indeed, growing cities and hydropower generation provide a much stronger socioeconomic justification for IBTs than the need for producing more food. Urbanization will thus make IBTs economically viable and politically compelling, although the shape of these IBTs may be different from the proposal currently under discussion. There seems little India will be able to do to avoid either IBTs or water infrastructure investment scales comparable to—or even exceeding—the present proposal.

References

Amarasinghe, U, A.; Sharma, B.; Aloysius, N.; Scott, C.; Smakhtin, V.; de Fraiture, C. 2005. *Spatial variation in water supply and demand across river basins in India*. Research Report 83. Colombo, Sri Lanka: International Water Management Institute

Amarasinghe, U. A.; Shah, T.; Singh, O.P.; Bhaduri, A. 2006. Changing consumption patterns in India and Implication for water demand (Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India').

Autobee, R. 1996. Colorado-Big Thompson Project, United States Bureau of Reclamation (USBR), Denver, Colorado, USA www.usbr.gov/dataweb/html/cbt1.html#CO

Bagla, P. 2006. Controversial Rivers Project Aims to turn India's Fierce Monsoon into a Friend. *Main Story: Going Against the Flow by Richard Stone and Hawk Jia. Science* Vol. 313, 25 August, 2006. *Verghese, B.G. 2003*. Exaggerated Fears on 'Linking Rivers'. Himal SouthAsian, September 2003. http://www.himalmag.com/2003/september/response.htm

Bandyopadhyaya, J.; Perveen, S. 2003. The Interlinking of Indian Rivers: Some Questions on the Scientific, Economic and Environmental Dimensions of the Proposal. Paper presented at Seminar on Interlinking Indian Rivers: Bane or Boon? at IISWBM, Kolkata, June 17, 2003. SOAS Water Issues Study Group, Occasional Paper No. 60.

Colorado State University. 2006. http://waterknowledge.colostate.edu/histbigt.htm

Earle, A.; Turton, A. 2005. No duck. No dinner: How Sole Sourcing Triggered Lesotho's Struggle against Corruption. World Water Week, Stockholm.

Falkenmark, M.; Lundqvist, J.; Widstrand, C. 1989. Macro-scale water scarcity requires micro-scale approaches: Aspects of vulnerability in semi-arid development. *Natural Resources Forum* 13 (4): 258_267.

FAO (Food and Agriculture Organization). 2006. FAOSTAT Database, Rome, Italy: FAO

GOI (Government of India). 1999. Report of the National Planning Commission: Integrated Water Resources Development. India: Government of India.

Hornby, B. 1993. Water Policy Has Changed — Attitudes will Follow. *Denver Post,* July 11 1993, Colorado, USA.

ICOLD (International Commission of Large Dams). 2000. World Register of Dams 1998: Updating 2000 for China. Paris: International Commission on Large Dams.

IUCN (The World Conservation Union) 2003. The Lesotho Highlands Water Project: Environmental Flow Allocations in an International River. www.waterandnature.org/flow/cases/Lesotho.pdf

IWMI (International Water Management Institute). 2000. World water supply and demand 1995 to 2025. Draft report prepared for World Water Vision. Colombo, Sri Lanka: IWMI

Iyer, R. 2003. Water: Perspectives, Issues Concerns, at New Delhi, India: Sage Publications.

Kumar, D.; Singh, O.P.; Samad, M.; Purohit, C.; Didyala, M. S. 2006a. Water Productivity of Irrigated Agriculture in India: Potential areas for improvement. (Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India').

Kumar, D. M.; Samad, M.; Amarasinghe, U.; Singh, O.P. 2006b. Water Savings and Yield Enhancing Technologies: How Far Can They Contribute to Water Productivity Enhancement in Indian Agriculture? (Draft prepared for the IWMI-CPWF project on, Strategic Analysis of National River Linking Project of India).

Mahmood, A.; Kundu, A. 2006. Demographic Projections for India 2006-2051: Regional variations (Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India').

Mochebelele, R T. 2000. Lesotho Highlands Water Project- Concerns and Benefits of Dams including the Environmental and Social Impacts and the Associated Mitigation Measures for Sustainability. World Commission on Dams. www.dams.org/kbase/submissions/sublist.php?rec=ins098

Nair, R.; Radhakrishna, M.D. 2005. Interlinking of Rivers for Mitigation of Droughts. In *Volume I – Water for Life with Special Reference to Interlinking of Rivers.* Proceedings of the Eleventh National Water Convention of India, May 11, 2005. New Delhi, India: National Water Development Agency.

NWDA (National Water Development Agency). 2006. "The Need", www.nwda.gov.in.

Rath, N. 2003. Linking of Rivers: Some Elementary Arithmetic. *Economic and Political Weekly* 38 (29): 3032-303.

Shah, T.; Aditi, D. R.; Asad, S. Q.; Wang, J. 2003. Sustaining Asia's Groundwater Boom: An Overview of Issues and Evidence. *Natural Resources Forum,* 27 (2003): 130–140.

Shiva, V. 2003. *River Linking: False Assumptions, Flawed Recipes. New Delhi, Navdanya.* http://www.navdanya.org/articles/false_assumptions.htm

Sharma, B.; Rao, K.P.; Vittal, K.P.R.; Amarasinghe, U. A. 2006. Rain-fed Potential in India (Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India').

Sinha, S.K.; Sinha, A.K.; Chandra, S. 2005. Interlinking of Rivers- Issues and Challenges, In *Volume I – Water for Life with Special Reference to Interlinking of Rivers.* Proceedings of the Eleventh National Water Convention of India, May 11, 2005. New Delhi, India: National Water Development Agency.

Snaddon, C.D.; Davis, B.R.; Wishart, M. 1999. *A global overview of inter-basin water transfer schemes, with and appraisal of their ecological, socio-economic and socio-political implications and recommendations for their management*. Water Research Commission, Technology Transfer Report TT120/00. Pretoria, South Africa: Water Research Commission.

Smakhtin, V.; Anputhas, M. 2006. A Pilot Assessment of Environmental Flow Requirements of River Basins. Draft prepared for the IWMI-CPWF project on ‘Strategic Analysis of National River Linking Project of India.

Verghese, B.G. 2003. Exaggerated Fears on ‘Linking Rivers’. Himal South Asian, September 2003. http://www.himalmag.com/2003/september/response.htm

Vombatkere, S.G. 2003. Interlinking: Salvation or folly? http://www.indiatogether.org/2003/ jan/ wtr-sgvintlink.htm

WCD (World Commission of Dams). 2000. Dams and Development. A New Framwork for Decision-Making. London, UK: EARTHSCAN.

India’s Water Supply and Demand from 2025-2050: Business- as- Usual Scenario and Issues

[1]*Upali A. Amarasinghe*, [1]*Tushaar Shah*, *and* [2]*B.K.Anand*
[1]*International Water Management Institute, New Delhi, India*
[2]*Consultant, Bangalore, India*

Introduction

For many reasons, India and China have had a central place in global food and water supply and demand projections. First, constituting more than one-third of the world’s population, they are the two most populous countries in the world. And, by the middle of this century they need to feed 700 million more people. Second, both countries have huge economies. Their economic growth in the recent decades—since the 1970s in China and since the 1980s in India—has been remarkable. With booming economies, people’s expenditure patterns are changing and so do their lifestyles. Rapid urbanization is also adding fuel to these changes. As a result, food consumption patterns are changing—changes a traditional country like India would not have imagined a few decades ago. The changing food consumption patterns are so significant that they have a considerable impact on future food and water demands. Third, and perhaps the most critical, is that both countries have significant spatial mismatches between their populations and their water resources; less water is available in places where more people live and much of the food is grown. Thus, the manner in which India and China meet their increasing food and water demands have been the major focus of many recent food and water demand projections both at the global scale (IWMI 2000; Rijsberman 2000; Rosegrant et al. 2002; Seckler et al.1998) and at the national scale (Bhalla and Hazelle 1999; Dyson and Hanchate 2000; GOI 1999).

On account of the rapid economic and demographic changes, the food and water demand projections of India and China need regular updating. For the base year, many recent projection studies used information relevant to the late 1980s and up to the early 1990s. One such study is the 1998 water demand projections of the National Commission of Integrated Water Resources Development (NCIWRD)—(GOI 1999), which considered a blueprint for water resources management and planning in India. For the base year, the NCIWRD projections used data relevant to 1993-1994, while future projections were derived from trends relevant to the 1980s. However, many changes over the past decade, which were unforeseen at the time of the study, have affected the demand projections. In particular, for example, changes due to the economic liberalization of the early 1990s in India are only visible now. Today, India has an unprecedented economic growth (there has been an annual economic growth of 8 % to 9 % in the last few years). This kind of growth has rapidly changed, certain food and water demand drivers that are endogenous to India, such as food consumption and land use patterns, and that are exogenous to India, such as world food trade. Therefore, in this context, many of the past food and water demand projections need to be reassessed. This paper revisits India's water future assessment from 2025 - 2050. It incorporates the recent changes in food- and water-related drivers in the supply and demand assessment and also analyzes the sensitivity of future projections to changes in these demand drivers. This paper uses the PODIUMSIM model for projecting India's water future. The PODIUMSIM (the Policy Dialogue Model) methodology is a tool for simulating alternative scenarios of water future with respect to variations in the food and water demand drivers (see Annex 1 for more details). This analysis has the benefit of using the latest data on demography, by using the 2001 census (GOI 2003); on food consumption patterns from the latest consumption and expenditure surveys (GOI 2001); and on land use and production patterns from recent agriculture surveys (GOI 2004a 2004b). The major objectives of this paper are to:

- assess the current status of food and water supply and demand in Indian river basins;
- project the water future of India and assess the implications of the water demand projections on river basins; and
- assess the sensitivity of food and water demand projections to changes in the key demand drivers.

The rest of the paper is organized into four sections. The next (second) section presents the methodology and descriptions of the data used for simulating water demand in this paper. The third section describes the current situation of food and water accounting in India and her river basins. The fourth section relates the projected water future of India during the period 2025 to 2050. The BAU scenario, which describes the business-as-usual scenario water future, is mainly based on the recent trends of the food and water demand drivers. The final projection of water future is very sensitive to many of these drivers. Therefore, in the fifth section, we assess the sensitivity of the water future projections with respect to changes in the demand drivers. We conclude the paper with a discussion of policy implications.

Data and Methodology

Methodology

The PODIUMSIM simulates the water future scenarios of this paper. The model explores the technical, social and economic aspects of alternative scenarios of future water demand and supply at the sub-national level (see Annex 1 for details of the model). The sub-national units could either be the administrative boundaries such as states or hydro-ecological regions, or the hydrological boundaries such as river basins. The river basins are the units of assessment for this paper.

The PODIUMSIM model has four major components: crop demand, crop production, water demand, and water accounting. The four components are assessed at various temporal and spatial scales (Table 1).

Table 1. Spatial and temporal scale improvements of different components.

Component	PODIUMSIM model	
	Spatial scale	Temporal scale
Crop demand	National (rural/urban)	Annually
Crop production	River basin	Seasonally
Water demand		
Irrigation	River basin	Monthly
Domestic	River basin	Annually
Industrial	River basin	Annually
Environment	River basin	Annually/Monthly
Water accounting	River basin	Annually

The crop demand component assesses the future demand of 12 crops or crop categories. They include grain crops: rice (milled equivalent), wheat, maize, other cereals, and pulses; and non-grain crops: oil crops (including vegetable oils as an oil crop equivalent), roots and tubers (dry equivalent), vegetables, fruits, sugar (processed) and cotton (lint). The major drivers of this component are the rural and urban population, the nutritional intakes (calorie supply) from grains, non-grains and animal products, the per capita consumption of different crop categories, and the feed conversion ratio (which indicate the quantity of feed used for producing 1,000 kcal of calorie supply).

The crop production component assesses the irrigation and rain-fed crop outputs of the 12 crop categories. The crop area and the yields under irrigated and rain-fed conditions are the main drivers of this component. The production component shows, first, the production surplus or deficit in the river basins, and then the aggregate at the national level. The production surplus or deficit at the national level shows the available quantity for export, stocks or import requirements.

The water demand component assesses the river basin water requirements for irrigation, and domestic, livestock, industrial and environmental sectors. The crop water requirement is first estimated at the district level for the 12 crop categories and the other irrigated crops, which mainly include fodder. The district estimates are then aggregated to estimate the river-basin-level estimates. The major parameters of the irrigation crop requirements are the crop irrigated area, crop calendar, crop coefficients, potential evapotranspiration and the 75 % exceedence probability rainfall. The crop water requirements in the surface water and groundwater irrigated areas divided by the respective project irrigation efficiencies indicate the irrigation demand. The population and per capita domestic water demand drivers can provide an estimate as to the domestic water demand change, while the total livestock population and average per head water requirement can indicate the approximate livestock water demand.

The PODIUMSIM model accounts the potentially available water resources of different river basins with respect to consumptive use, return flows of different sectors and their non-beneficial use, and the outflows.

Data

We use the year 2000 as the base year for our future projections. The 2000 database and the past trends of different drivers are derived using the data of various internal and external publications (Table 2).

Table 2. Types and sources of data used for the analysis.

Data	Sources	Reference
Urban and rural population	2001 Census records andthe projections of Mahmood and Kundu 2006	GOI 2003; Mahmood and Kundu 2006
Crop consumption (calorie supply, food and feed consumption of different crops) (NSSO) reports	Nutritional intakes and per capita consumption data of FAOSTAT database of the Food and Agriculture Organization (FAO) and the various rounds of National Sample Survey Organization	FAO 2005a GOI 1996 GOI 2001
Land use statistics, crop area and crop yield	Crop production data of the FAOSTAT database and the various issues of Agricultural Statistics at a Glance, Fertilizer Statistics and Crop Yield Estimation Surveys of Principal Crops	FAO 2005a; GOI 2004, FAI 2003a, FAI 2003b, FAI 2003c, FAI 2003d
Rainfall, potential evapotransiration and land use map	International Water Management Institute World Water and Climate Atlas	IWMI 2001 IWMI 2005
Crop calendar, crop coefficients	AQUASTAT database of the FAO and FAO Irrigation and Drainage Paper No. 56	FAO 2005b; FAO 1998
Basin runoff	Central Water Commission of India	CWC 2004FAO 2003

The river-basin-wise data in this paper are derived by aggregating the information of the districts falling within the area of the river basins. In general, most of the information, except water supply, is collected and available at the level of the administrative boundaries. In this paper, these data are available at the district level. When districts overlap with two or more rive basins (Figure 1), the district population is divided according to the geographical area of the river basins, and the crop area is divided according to the net sown area of the districts falling within different river basins. The net sown area of river basins is estimated using the land use map of India (IWMI 2005).

Figure 1. State and land use cover map of India overlaid on major river basins.

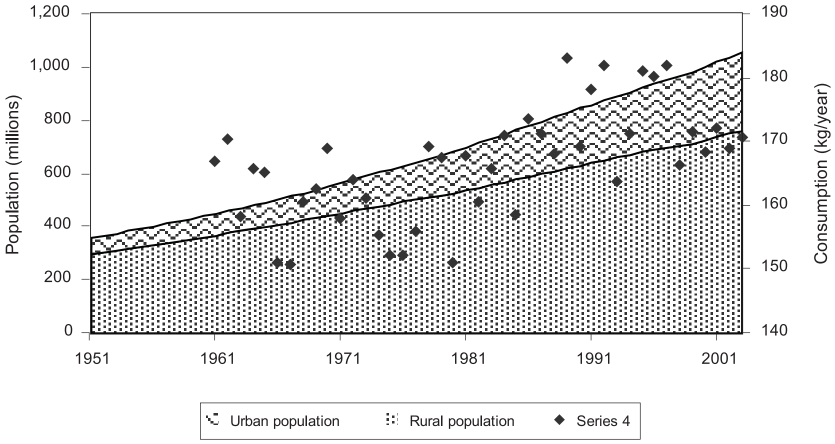
Food and Water Accounts—Past Trends and Current Status

Food Demand

The growth of food grain demand in India has been decreasing in recent years. The grain demand increased 3.1 % annually in the 1980s and the total population increased at 2.2 % during the same period. Decreasing trends of food grain consumption per person (Figure 2) however, led to a 1.3% annual decline in the growth of total grain demand in the 1990s, even though the population growth during this period was similar to the 1980s i.e. increased annually at 2.1 %.

Three factors contribute to the decline in food grain demand. First, the per capita grain consumption in both the rural and the urban population itself is decreasing. The rural and urban food grain consumption in the 1900s has been declining at an annual rate of 0.9 and 0.4% respectively, (GOI 1996 and 2001). Although the decline in rural food grain consumption is expected to continue, the rate of urban consumption is likely to stabilize soon (Amarasinghe et al. 2006; Dyson and Hanchate 2000). The rural-urban consumption differential and the rapid urban population growth are the second and third factors, contributing to the declining food grain demand.

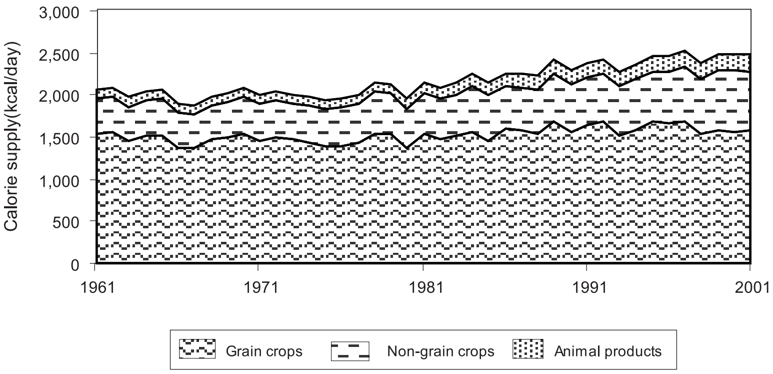
Figure 2. Growth of population and per capita food grain consumption in India.



Source: FAO 2005
UN 2005

In spite of the declining intake of food grains in the diet, the average nutrition supply per person in India has increased steadily over the last decade (Figure 3). Increased consumption of non-grain crops such as vegetables and fruits, and animal products such as milk, poultry and eggs has contributed to most of the increase in total calorie supply. Increasing income and rapid urbanization are expected to Further increase the nutritional supply per person in the future (Dyson and Hanchate 2000; Amarasinghe et al. 2006).

Figure 3. The calorie supply per person from grain crop, non-grain crop and animal products.

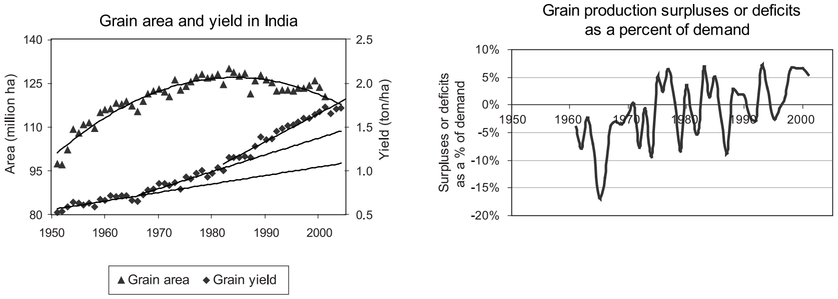


Source: FAO 2005

Food Production

Today, India is self-sufficient in most of her food requirements. Grain production, which has consistently outpaced grain demand over the last three decades, increased to 207 million metric tons (Mmt) by 2000. Area expansion and yield growth were both contributing factors to such production increases until the mid-1980s. Such increases have led, India, after a long period of food grain deficits, to record grain production surpluses in the mid-1970s (Figure 4). Although grain area growth stopped after the mid-1980s, growth in yield has been pushing India to record consistent grain surpluses even after the 1980s (Figure 4).

Figure 4. Grain area and yield and the production surpluses or deficits in India.



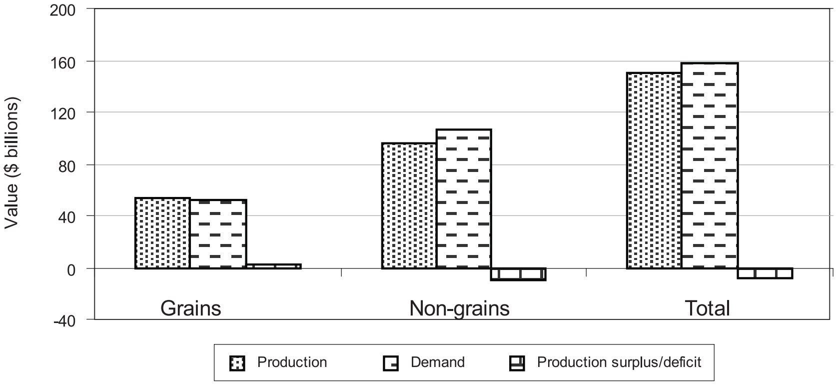
Source: FAO 2005

Although in the past, grain had a preeminent place in Indian agricultural production, this influence is slowly changing. The share of the value of grain production[1] has decreased over time, and is only 36 % now. Though the production value of non-grain crops, including oil crops, roots and tubers, vegetables, fruits, sugar and cotton is much higher(US$95 billion in 2000) than that of grain crops—non-grain crops recorded a production deficit of 9 % of total consumption in the year 2000 (Figure 5). India imports a substantial part of its edible oil requirements at present. However, overall, India is more or less self-sufficient in all crops, recording only a 3 % production deficit in the year 2000. As regards grain crops, India has been importing a substantial quantity of pulses in recent years, and exporting surplus rice and wheat.

---

[1] The value of total crop production under the PODIUMSIM methodology is estimated using the average export prices/kg of different crops in 1999, 2000 and 2001 (FAOSTAT 2005a). The average export prices of rice, wheat, maize, other cereals, pulses, oil crops (including vegetable oils), roots and tubers (dry equivalent), vegetables, fruits, sugar (refined) and cotton (lint), respectively, are US$/mt 375, 107, 176, 203, 199, 559, 1,631, 285, 776, 268 and 1,110

Figure 5. Value of crop production and demand and production surpluses or deficits of India.



Although India is self-sufficient in her food requirements, significant production surpluses and deficits exist in different river basins. Although food security is indeed a national issue, regional imbalances are important in the context of increasing water scarcities and virtual water trade is an important factor in terms of water use. Virtual water trade is the transfer of water, embedded in commodities, through trade, and could also become an instrument for mitigating the water scarcities of different regions or countries (Allan 1998; de Fraiture et al. 2004; Kumar and Singh 2005). The regions with water surpluses, in general, could benefit from virtual water trade, although the practices in reality so far suggest the opposite. The Indus Basin is a clear case of where the impact of virtual water trade has transformed what was perhaps a water-deficit basin in to a water-surplus one. The Indus meets more than 80 % of the grain production deficits of other basins, which are also classified as physically water-scarce. But with increasing demand from other sectors, this picture could change in the future. At present, this imbalance of the virtual water trade between basins is partly due to low productivities in the production-deficit basins and the scarcity of land is also a contributing factor. But by improving low productivities in the water-surplus areas, the virtual water trade could indeed ease regional water scarcities.

Water Supply

India's water availability varies substantially across the regions, and over time. Of the total rainfall of about 4,000 BCM, 1,260 BCM are estimated to be available as the internally renewable water resources (IRWR[2]). Adding the inflows from, and subtracting the flows out to other countries, India records 1,953 BCM of rainfall as the total renewable water resource

---

[2] The total renewable water resources consist of the internally renewable water resources and net inflows to the country. The internally renewable water resource is the average annual flow of rivers and recharge of aquifers generated from the endogenous precipitation .The commission's estimate of TRWR, based on the Central Water Commission reports, is about 1,953 BCM (GOI 1999; CWC 1998).

(TRWR)—(GOI 1999; CWC 2004; FAO 2003). In 1950, India recorded 5,400 m^3 of water per person, and was ranked 126 out of 154 countries in the world in terms of per capita water availability (Gardener-Outlaw and Englemen 2006). Today (2000), per capita water availability has decreased to 1,900 m^3/person, although, at the national level, this figure is a sufficiently high value of total renewable water resource availability. Despite a considerable spatial variation of rainfall, many river basins record significantly lower per capita water availability in terms of the TRWR (Amarasinghe et al. 2005).

In spite of the large TRWR, potentially utilizable water resources (PUWR) in India are only a fraction of the TRWR. The Brahmaputra and Megna basins cannot physically store their massive water resources (677 BCM or 35% of India's TRWR), and therefore due mainly to such physical constraints, only 18 % of the TRWR is potentially utilizable there. Most other basins, especially those in the peninsular, receive their IRWR from the 2 to 3 months of monsoonal rains. As a result, some basins have a very low PUWR. In fact, each of as many as eight basins had a per capita PUWR less than 1,000 m^3 of water person in the year 2000, a level indicating severe regional water scarcity according to Falkenmark et al. (1989). Overall, the PUWR of surface water and groundwater that can be diverted to various human and other uses are estimated as 1,030 BCM (CWC 2004).

Water Withdrawals

Irrigation is still the largest consumptive water use sector in India. Irrigation contributed to 90% of the total withdrawals of 680 BCM in 2000. The domestic and industrial sectors contributed 5 % each.

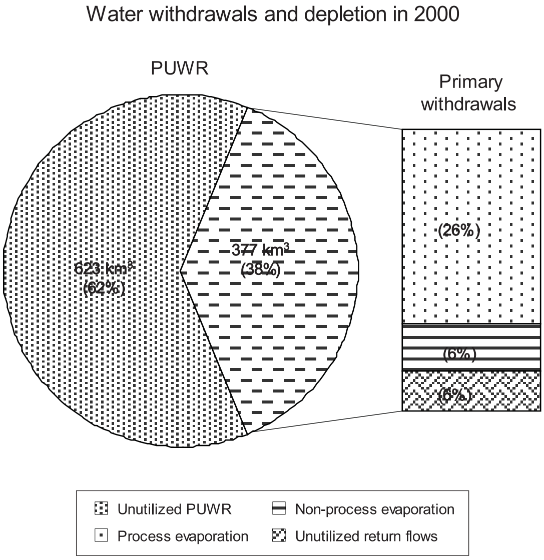
Groundwater irrigation, which expanded rapidly in the last few decades, forms a major part of the water withdrawals in many river basins. At present, more than 60 % of the total irrigated area is groundwater irrigated. However, with relatively higher project efficiencies than surface irrigation, groundwater contributed to only 45 % of the total irrigation withdrawals. Still, due to over-abstraction, some basins are facing severe regional water table depletions (Amarasinghe et al. 2005).

Water Accounting

The PODIUMSIM model uses the water accounting framework of Molden (1997) to show how water in different river basins is depleted through various processes. The *process evaporation*—the evapotranspiration from irrigation and the transpiration from the domestic and industrial sectors, accounts for 26 % of the total PUWR (Figure 6). The *non-process evaporation*—the evaporation from swamps, homesteads, canals and reservoir surfaces—constitutes another 6 % of the PUWR. The *outflows*, the return-flows of the water diverted (6%) and the unutilized PUWR (62%) account for the remainder of the PUWR.

In 2000, the 'degree of development', the ratio of primary withdrawals to the PUWR, of all basins was 38 %. A higher degree of development indicates: a) physical water scarcity, i.e., whether adequate quantities of water are available for meeting future development without affecting the environment or other water users; and, b) the increasing costs of further water development. When the degree of development exceeds 60 %, the basins are classified to be physically water-scarce (Seckler et al. 1998; IWMI 2000).

Figure 6. Water accounts of the potentially utilizable water resources of all river basins in India.



Indeed, several river basins in India are already physically water-scarce, which include the Indus, Western Flowing Rivers Group 1(WFR1), Mahi and Sabarmati. The Indus Basin is physically water-scarce but it produces a substantial part of the nation's grain requirement. The Western Flowing Rivers, Group 1 (WFR1), Mahi and Sabarmati basins are physically water-scarce and are also recording deficits in crop production. Many river basins in India also experience unsustainable regional groundwater use. The groundwater abstraction ratios—the ratios of total groundwater withdrawals to the total recharge from rainfall and return flows—of many basins are significantly high. This indicates that certain regions experience unsustainable groundwater depletions.

Business-as-Usual Scenario from 2025-2050: Storyline

We begin the Business-as-Usual (BAU) scenario storyline with a quote from the Prime Minister of India, Dr. Manmohan Singh (Prime Minister's address to the Economic Summit 2005).

> *"…It is certainly within the realm of possibility that an appropriate combination of policies can raise the economic growth beyond 8 % easily. In fact, we should be targeting 10% growth rate in 2-3 years' time. In my view, this is eminently feasible, if we have the expected increase in savings rate and arising out of a young population, if we manage to make a quantum leap in the growth rate of our agriculture..."*

The BAU scenario in this paper is, indeed, based on this rather optimistic economic growth assumption. It assumes that the contribution from the agriculture sector to the gross domestic product will further reduce, but that the benefits of higher economic growth will filter down to every sphere, and the government and the private sector will invest in accelerating the growth of agricultural productivity to make that quantum leap as suggested by the Prime Minister.

The BAU scenario assumes that the shifts in consumption pattern will continue with further urbanization and increasing income. The average Indian diet, in the future, will have more calorie supply from non-grain products, such as non-grain crops and animal products. Although food grain consumption decreases, the demand for feed grain, primarily maize, will increase with a higher intake of animal products in the diet.

The BAU scenario also assumes that groundwater expansion, which played a major role in contributing to the livelihoods of many rural poor, will continue. But, the emerging groundwater markets, scarcity of the resource, the increasing cost of pumping, and the spread of micro irrigation technologies, will make groundwater use more efficient. The BAU scenario assumes that unsustainable groundwater development patterns emerge in other regions, as we see today in the states of Punjab, Haryana, Rajasthan and Tamil Nadu.

Table 3 shows the growth rates assumed for the key drivers that influence future water demand. Recent trends, both temporal and spatial, across districts and states, are the basis for the magnitude of change in these drivers. Here we give a brief description of the future directions of the key drivers.

Demographic Change

India’s population is increasing but will stabilize in the middle of this century. The BAU scenario assumes that the population will increase at 1.3 % over the period 2000-2025, and at 0.52 % between 2025 and 2050. The population growth is expected to stabilize in the early 2050s, although several large states will have peaked in their population growth well before the year 2050, and certain states will even record declining trends as early as the 2030s and 2040s. Urbanization will also continue to expand, and slightly over half of India’s population will live in urban areas by 2050 (Mahmood and Kundu 2006).

Many of the states with a declining population before the 2050s are in the south and east, and also have a high urbanization growth. These states are located in river basins, which are experiencing regional water scarcities at present, and are also expected to record the highest rate of migration from agriculture to employment in the nonagriculture sector. In fact, Sharma and Bhaduri (2006) have shown that the odds of rural youth moving out of agriculture are high in areas where water scarcities are more pronounced, and where nonagricultural employment opportunities in the neighborhood are high. For the purpose of the BAU scenario, we assume that this demographic pattern will continue.

Income Growth

The economic growth in India shows contrasting patterns before and after economic liberalization. India’s per capita Gross Domestic Product (GDP) increased at 1.9 % annually in the pre-liberalized economy (1961-1990) and at 3.8 % thereafter. Since 1991, the per capita GDP growth has been steady and has fluctuated from 3 % to 6 % annually. The International Food Policy Research Institute (IFPRI), using the IMPACT model, projects India’s total GDP (in 1995 constant prices) to increase at 5.5 % between 1995 and 2020 (Rosegrant et al. 2001).

Table 3. Growth in food and water demand drivers.

Water demand drivers	2000	2025 projection	2050 projection
Demography			
Population (million)	1,007	1,389	1,583
Urban population (%)	28	37	51
Economic growth			
GDP growth (US$1995 prices)	463	1,765	6,735
Nutritional intake			
Total calorie supply (Kilo calories per person per day (kcal/pc/day)	2,495	2,775	3,000
Contribution of grain crops (%)	65	57	48
Contribution from non-grain crops (%)	28	33	36
Contribution from animal products (%)	8	12	16
Food consumption/per capita (kg/yr)			
Grains	172	166	152
Rice	76	74	79
Wheat	58	58	58
Maize	10	8	4
Other coarse cereals	17	15	9
Pulses	11	12	12
Oil crops (oil crop equivalent)	41	64	73
Roots and tubers	6	8	12
Vegetables	69	102	114
Fruits	40	49	67
Sugar	26	28	33
Cotton	2.1	2.8	3.8
Feed conversion ratio (kg of feed grainsper 1,000 kcal of animal products)			
Conversion ratio	0.12	0.27	0.40
Crop area (Million ha)			
Net sown area	142	142	142
Net irrigated area	55	74	81
Net groundwater area	34	43	50
Net canal and tank area	21	31	31
Gross irrigated area (GIA)	76	111	117
Gross crop area (GCA)	189	208	210
Grain crop area - % of GCA	65	58	57
Grain irrigated area - % of GIA	43	49	52
Crop yield (tons/ha)			
Average grain yield	1.7	2.4	3.1
Irrigated grain yield	2.6	3.6	4.4
Rain-fed grain yield	1.0	1.3	1.8
Project irrigation efficiency (%)			
Surface water	30-45	35-50	42-60
Groundwater	55-65	70	75
Domestic water demand			
Human water demand (m^3/person/year)	31	42	61
Livestock water demand (BCM)	2.3	2.8	3.2
Industrial water demand (m^3/person/year)	42	66	102
Environmental water demandMinimum river flow - % of mean annual runoff	-	6-45	6-45

We assume that India’s per capita income will increase at 5.5 % annually over the next 50-year period. The per capita GDP will increase from US$463 (in 1995 prices) in 2000 to about US$1,765 by 2025 and to about US$6,735 by 2050. We also assume that the contribution from the industrial and the service sectors to the overall economic growth will continue to increase. By 2050, the industrial sector GDP will contribute to about 40 % of the total GDP.

Consumption Patterns

India’s nutritional intake patterns are fast changing. The consumption of food grains, which provide a major part of the daily nutritional intake, is decreasing in both the rural and the urban areas. On the other hand, the consumption of non-grain crops, such as vegetables, fruits and oil crops, and animal products such as milk, poultry and eggs, is increasing (Amarasinghe et al. 2006; Dyson and Hanchate 2000).

We expect high income growth and urbanization will continue to contribute to further changes in the food consumption patterns. The total nutritional intake will continue to increase, but the share of grain products in the consumption basket will diminish further. As much as 54 % of the total calorie supply will be derived from non-grain products by the year 2050, compared to the 36 % at present (see Amarasinghe et al. 2006 for a detailed estimation). We also assume, as did Rao (2005) that the differences in urban and rural consumption patterns will still exist, but the gap will be much narrower by 2050. As a result of these factors, rural nutrition impoverishment will also reduce substantially.

Projections on the increase of animal products consumption will have a significant impact on the feed grain demand. The feed grain conversion factor-the quantity of grains, primarily maize, required for producing 1,000 kcal of animal products, was only 0.12 kg/1,000 kcal in 2000. Based on recent trends, Amarasinghe et al. (2006) projected that the feed conversion ratio would increase to about 0.40 kg/1,000kcal by 2050, which is the ratio for certain upper to middle income developing countries, such as China, at present.

National Food Security

The BAU scenario assumes that national self-sufficiency in individual crops will no longer be a concrete goal. Crop diversification, which started spreading in the last decade, will continue at a faster pace. Farmers will shift cropping patterns to grow more cash crops, which best suit the available land and water resources, and the prevailing market conditions. As a result, the share of grain area, both in the gross crop area and the irrigated area will diminish.

Some crops are expected to have production deficits, as at present. But, at the national level, the increase in income from high-value crops is sufficient to pay for the imports needed to cover any deficit in other crops.

Crop Area Growth

The BAU scenario assumes that the net sown area will remain the same, that being at the present level of 142 million hectares (Mha). But irrigation expansion is likely to continue and will remain a major contributor to growth in the gross irrigated and crop areas.

Groundwater irrigation has spread to the rain-fed areas, some of which do not have substantial surface irrigation return flows. And by 2025, gross groundwater irrigated area would increase to 60 Mha, and by 2050 this will increase to 70 Mha. Indeed, the BAU scenario for growth in the net groundwater irrigated area has been very much below the trend level during the past few years. Our assumption in this regard is influenced by the current potential of groundwater irrigation coverage. However, with artificial recharge, groundwater irrigation potential could increase more in the future. In a later section, we assess the sensitivity of the BAU water demand projections to various groundwater irrigation growth scenarios.

The surface irrigation coverage in the BAU scenario will also increase. The projects that are under construction now will contribute to this increase. The IXth 5- year plan (2002-2007) alone envisages adding 10 Mha to the surface irrigation potential (GOI 2004). The net canal irrigated area coverage is expected to increase from 17 to 27 Mha over the period 2000-2025. The same surface irrigation coverage is assumed for the period between 2025 and 2050. A major part of the rest of the net sown area—what is at present classified as rain-fed—receives supplemental irrigation during periods of water stress, which is crucial to crop growth.

The BAU scenario projects that the irrigation coverage will continue to increase to approximately 55 % of the total crop area by 2050, from its present level of 41 %. We also assume that the supremacy of the grain crop in irrigated agriculture will diminish and the irrigation coverage of grain crops will decrease from the present level of 71 % to approximately 56 and 54 % by 2025 and 2050, respectively (see Annex 2 for detailed estimations).

Crop Yield Growth

The grain crop yield growth has been declining in recent decades—3.6 % in the 1980s and 2.1 % in the 1990s. The BAU scenario assumes that the declining trends will continue, but not at such a steep trend as is seen in the last two decades. The growth of grain yield would decline to 1.4 and 1.0 % annually in the first and second quarters, respectively, of this century. With these growth rates, average grain yields will increase from the year 200 level of 1.7 tons/ha to 2.4 tons/ha by 2025, and 3.2 tons/ha by 2050.

In spite of decreasing trends in the past, and also the bleak assumptions of the BAU scenario, we, however, believe that there is substantial scope for increasing the yield beyond this limit. It is clear that there is a significant gap between the highest and lowest actual yields, and further between the actual and potential yields (Agrawal et al. 2000). The investments, both private and public, that the Prime Minister mentioned, in the future will focus on small-scale infrastructure and technologies that will greatly enhance crop yields. Micro irrigation technologies offer opportunities for significant yield growth (Kumar et al. 2006; Narayanmoorthy 2006; INCID 1998). The expanding groundwater use could also contribute significantly to increasing the irrigated yield. And supplementary irrigation, through water harvesting, at critical periods of water stress, can substantially boost rain-fed yields (Sharma et al. 2006). Moreover, farmers will have an incentive to increase crop productivity to benefit from the increasing internal and external food trade. Later we assess the sensitivity of crop production to the assumptions of yield growth under the BAU.

Irrigation Efficiency

The information available to date, suggests that surface project irrigation efficiency has not improved much, while many groundwater irrigation areas have relatively higher efficiencies. As resources become scarce and also expensive, water saving technologies spread fast, resulting in further improvements in groundwater irrigation efficiency. The BAU scenario assumes that groundwater efficiency would increase to 75 % by 2050 from its present level of 65 %. Surface project irrigation efficiency is also assumed to increase from its present level of 30-40 % to about 50 % in 2050.

Domestic Water Demand

With increasing household income and increasing contributions from the service and industrial sectors, the water demand in the domestic and industrial sectors could increase substantially. We assume that the average domestic water demand would increase from 85 liters per capita per day (lpcd) in 2000, to 125 and 170 lpcd by 2025 and 2050, respectively. The BAU scenario approach differs from the approach adopted by the NCIWRD commission. They assumed norms where the rural domestic water demand in 2025 and 2050 are assessed at 70 and 150 lpcd, respectively, and the urban water demand at 200 and 220 lpcd, for 2025 and 2050 respectively. They also assumed 100 % coverage of domestic water supply for both the rural and the urban sectors. At this rate, the average per capita water demand in 2025 and 2050 is estimated to be 126 and 191 lpcd, respectively.

The domestic water demand includes the livestock water demand as well, which we assume to be 25 liters per head for the cattle and buffalo population. The livestock population is projected at the rate of animal products calorie supply. We estimate the livestock water demand to increase from 2.3 BCM in 2000 to 2.8 and 3.2 BCM by 2025 and 2050, respectively.

Industrial Water Demand

In a rapidly booming economy, we expect the contribution of the industrial sector to increase very much, and the industrial water demand to also increase accordingly. However, the dearth of information—the types of industries, their growth, water use and the extent of recycling—is a constraint for future projections in the context of increasing economic growth. The NCIWRD commission, based on a small sample of industries and their water use, projected that industrial water demand would increase from 30 BCM in 2000, to about 101 and 151 BCM by 2025 and 2050, respectively.

However, an analysis using the global trends show that, with the present economic growth rates, the per capita industrial water demand could increase from 42 m^3/person in 2000, to about 66 and 102 m^3/person by 2025 and 2050, respectively or the total industrial water demand to increase to 92 and 161 BCM by 2025 and 2050, respectively. The BAU scenario too assumes these growth rates.

Environmental Water Demand

As a result of increasing economic activities, the quality and quantity of water in some rivers are at a threateningly low level. However, with increasing campaigns by NGOs and civil societies, awareness of water-related environmental problems is increasing. As a result, the water demand for the environment could increase rapidly. At the least, we believe that a minimum flow requirement (MFR) provision will be established in most river basins. We use the MFR estimates of Smakhtin and Anputhas (2006) as a guide for assessing the BAU scenario of the environmental water demand.

The MFR of Smakhtin and Anputhas (2006) depends on the hydrological variability and the environmental management class that the river ought to maintain. We estimate Environmental Flow Requirement (EFR) using the guidelines for the environmental management class C, which is classified as for a ‘moderately disturbed’ river. In class C, the habitats and the biota of the rivers have already been disturbed, but the basic ecosystem functions are intact. And the management perspective for Class C is to preserve the ecosystem to such an extent that multiple disturbances associated with the socioeconomic development are possible. This management class, in general, proposes an MFR in the range of 12 to 30 % of the mean annual runoff. In particular, the Brashmaputra River basin’s MFR is estimated as 46 %, and for the Mahi River it is 7 %. We use these guidelines for estimating the environmental water demand to be released from the potentially utilizable water resources.

Business-as-Usual Scenario Projections

Water Demand

The total water demand of the BAU scenario is projected to increase to 22 % by 2025, and 32 % by 2050 (Table 4). A major part of the additional water demand is for the domestic and industrial sectors. The water demands of the domestic and industrial sectors will account for 8 % and 11 % of the total water demand by 2025. And these shares will increase to 11 % and 18 %, respectively, by 2050. Moreover, the domestic and industrial sectors will account for 54 % of the additional water demand by 2025, and more than 85 % by 2050.

Table 4. BAU scenario water demand projections.

Sector	2000		2025		2050	
	Total	% from groundwater	Total	% from groundwater	Total	% from groundwater
	BCM	%	BCM	%	BCM	%
Irrigation	605	45	675	45	637	51
Domestic[a]	34	50	66	45	101	50
Industrial[b]	42	30	92	30	161	30
Total	680	44	833	43	900	47

Notes: [a]Domestic withdrawals include those for livestock water demand
[b]Industrial withdrawals include cooling needs for power generation

The BAU scenario projects significant water transfers from the irrigation sector to other sectors by 2050. The combination of higher irrigation efficiencies and large groundwater irrigated areas would result in a decrease of the irrigation water demand between 2025 and 2050. While the total irrigation demand would decrease by 38 BCM, the surface irrigation demand is estimated to decrease by 46 BCM. This surplus irrigation water is projected to be available for the domestic and industrial sectors.

Production Surpluses or Deficits

The total grain production under the BAU scenario in 2050 is estimated to be more than the total grain demand (Table 5). In 2050, the total grain production is estimated to be 2.0 % more than the estimated grain demand of 377 Mmt. The total production of non-grain crops, estimated in terms of the average export prices of 1999-2001, was 9.4 % less than the non-grain crop demand of 2000. And the production deficit of non-grain crops is projected to decrease to 6.3 % by 2050. Due to production deficits of non-grain crops, the total value of crop production is projected to be less than the demand of all crops i.e., approximately 4.0 % by 2025 and 2050.

Table 5. Crop demand and production surpluses or deficits.

Crop category	Demand			Production surpluses (+) or deficits (-) as a % of demand		
	2000	2025	2050	2000	2025	2050
Food grains (Mmt)	173	230	241			
Feed grains (Mmt)	8	38	111			
Total grains (Mmt)	201	291	377	2.8%	0.2%	2.0%
Grains (BUS$)[1]	52	73	90	3.3%	0.4%	3.4%
Non-grains (BUS$)[1]	106	198	284	-9.4%	-5.4%	-6.3%
Total (BUS$)[1]	158	272	374	-5.2%	-3.9%	-4.0%

Notes: [1] The value is in billion US$ and is expressed in terms of the average of export prices in 1999, 2000 and 2001. Totals include other components (seeds, waste etc) grain availability.

Among the grain crops, substantial production deficits are projected for other cereals and pulses (Table 6). The production deficit of other cereals is primarily due to the increase in demand of maize for livestock feeding – total maize demand is projected to increase from 5 Mmt in 2000 to 107 Mmt by 2050. However, the deficits of other crops are offset by production surpluses of

Table 6. Production, demand and production surpluses or deficits of different crops.

Crop	Production			Demand			Production surpluses or deficits - % of demand		
	2000	2025	2050	2000	2025	2050	2000	2025	2050
	Mmt	Mmt	Mmt	Mmt	Mmt	Mmt	%	%	%
Rice	89	117	143	82	109	117	8	7	22
Wheat	72	108	145	67	91	102	8	18	41
Other cereals	32	49	78	37	73	137	-16	-33	-43
Pulses	13	18	19	14	18	21	-5	-3	-7
Grains	206	292	385	200	291	377	3	1	2
Oil crops	31	73	97	48	103	133	-35	-30	-27
Roots/tubers	7	14	26	7	13	24	-3	10	7
Vegetables	74	150	227	75	150	189	-1	0	20
Fruits	46	83	106	47	78	123	-1	6	-14
Sugar	30	46	60	26	42	55	14	9	10
Cotton	2	4	6	2	4	6	-12	-2	-3

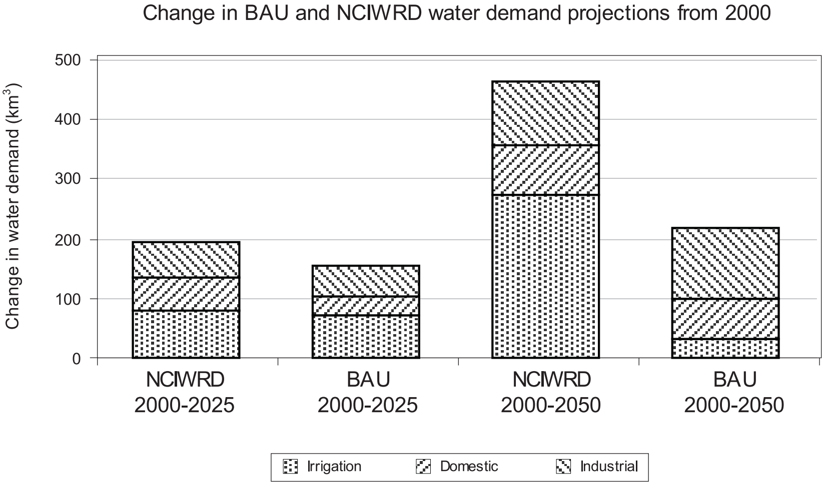
Sources: 2000 data are from the FAOSTAT database (FAO 2005a); the 2025 and 2050 data are estimated by the author.

rice and wheat to maintain overall grain production surpluses by 2050 (Table 5). Among non-grain crops, oil crops are expected to have substantial production deficits.

BAU Projections: Comparisons

The BAU projections are first compared with the projection of the NCIWRD commission (GOI 1999). Figure 7 shows the incremental water demand of irrigation, domestic and the industrial sectors projected for the time frames of 2000 to 2025 and 2000 to 2050. The striking difference between the projections for the two time frames is the irrigation demand. In both time frames, the projections up to 2025 have a similar irrigation demand increase, but the projections deviate significantly by 2050. While the BAU scenario projects a decreasing irrigation demand between 2025 and 2050, the NCIWRD commission projects an additional demand of 250 BCM by 2050.

Figure 7. Difference of water demand projections—BAU and NCIWRD high growth scenarios.



The differences in incremental irrigation demand in 2050 are due to several factors. First, the BAU scenario, based on recent trends, projects a decreasing food grain demand and an increasing feed grain demand. The NCIWRD commission projects a significant growth in food grain consumption. Both projections target nutrition security, but the BAU scenario projects a diversified diet, whereas the NCIWRD assumes a grain-dominated diet. The BAU scenario projects a 3,000 kcal per person per day average calorie supply by 2050, while the average calorie supply based on the NCIWRD assumptions could well be over 4,000 kcal per person per day by 2050. The latter is not a realistic goal to attain, at least according to present global consumption patterns, where even developed countries, with substantial animal products in the diet, consume about 3,600 kcal per day per person. Second, the commission has assumed self-sufficiency in grains, and has projected that much of the additional grain requirement for meeting self-sufficiency is to be produced under irrigation conditions. For this, they estimated 104 Mha of grain irrigated area, while the BAU scenario projected a grain irrigated area of only

79 Mha. Third, the BAU scenario assumes a rapid groundwater irrigation expansion, whereas a major part of the NCIWRD commission's projection is for surface irrigation. The commission assumed the surface water to groundwater ratio to be 55:45, while the BAU scenario projected a ratio of 40:60. Combined with area differences, the assumption of irrigation efficiencies has contributed to water demand differences.

We also compared the BAU scenario projections of this paper and those of the IMPACT ((International Model for Policy Analysis Commodities and Trade)-Water model (Rosegrant et al. 2002). Although, the total water demand projections for 2025 of the two scenarios are similar (IMPACT-Water model projects 822 BCM by 2025), we find that the assumptions leading to demand estimations and the sectoral demand projections themselves are different.

The IMPACT model projects 76 Mha of potential irrigated area for India by 2025. However, the gross area has already reached 76 Mha as per the base year (2000) data for the BAU scenario of this paper. The IMPACT-Water model also projects the cereal irrigated area to increase to 48 Mha by 2025, but India's irrigated cereal area is already above this level, and in 2000, which is this paper's base year, the grain irrigated area was 54 Mha. The IMPACT - Water model has erred in its assumptions as regards key drivers by failing to consider the recent trends in groundwater development, which has in turn resulted in significant deviations between the IMPACT-Water model and BAU scenario projections irrigated crop area. As a result, the irrigation demand under the two projections is also at variance.

BAU Scenario and Regional Water Crisis

The BAU scenario assumed that groundwater irrigation would continue to increase, but at a reduced pace. Uncontrolled groundwater pumping, on the one hand, contributes to increasing gross irrigated area, crop yield and crop production and, on the other, contributes to physical water scarcities and groundwater-depletion- related environmental issues in certain basins. Figure 8 shows how the degree of development, the groundwater abstraction ratio, and the depletion fraction[3] of the PUWR change over the period 2000-2050.

Many river basins will be physically water-scarce by 2050. The degree of development of 10 river basins, comprising 75 % of the total population, will be well over 60 % by 2050. These water-scarce basins would have developed much of the potentially utilizable water resources by the second quarter of this century. And the different sectors in these basins would share a common water reallocation to meet the increasing demand. Indeed, the BAU scenario projects transfer of surface irrigation resources to domestic and industrial water use.

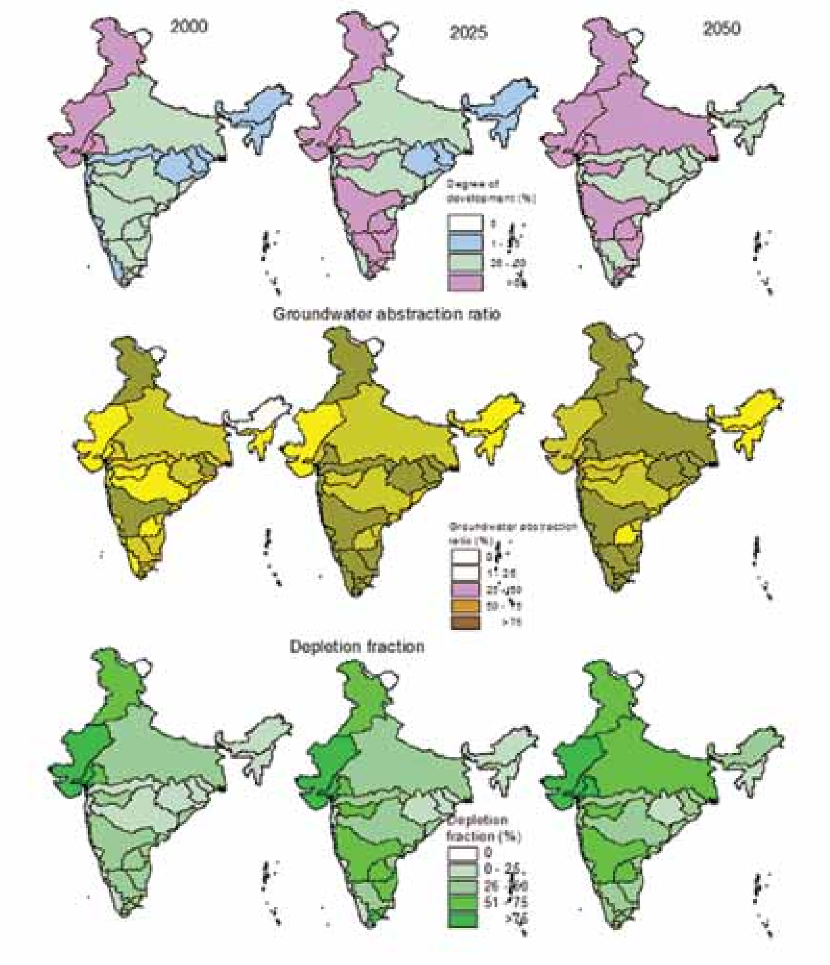
Increased groundwater irrigation would have severe detrimental effects on many basins. Groundwater abstraction ratios of many basins are significantly high. Given the current level of recharge, patterns of groundwater use for these basins are not sustainable. Indeed, the growth patterns under the BAU scenario could lead to regional water crises.

---

[3] Depletion faction in this paper is defined as process and non-process evaporation as a fraction of the PUWR.

The depletion ratios show where the water crises are severe. Several basins would deplete more than 60 % of the PUWR by 2050, and face severe water scarcities under the BAU scenario. The solutions for these river basins are: a) to increase crop productivity for every unit of water they use at present; b) to increase potential groundwater supply through artificial recharge methods; c) to concentrate on economic activities where the value of water is very high; and d) to get water transfers from the water-rich basins.

Figure 8. Degree of development, groundwater abstraction ratio and the depletion fraction in 2000, 2025 and 2050.



Water Supply with Environmental Water Demand

Environmental water demand often received scant attention in most demand projections and the absence of a clear methodology was a major constraint in this respect. The primary emphasis of meeting the water needs of other sectors is also to blame for this situation. The NCIWRD commission projections have a provision of 10 BCM—1 % of total demand;

Rosergrant et el. (2002) have allocated 6-15 % of the mean annual runoff; and other studies (Seckler et al. 1998; IWMI 2000) have highlighted environmental impacts by setting a threshold for the withdrawal limits. We updated the EFR demand of Indian river basins based on the guidelines of Smakhtin and Anputhas (2006).

Table 7 shows the environmental flow demands of the river basins, and the available water resources for other sectors if part of the environmental demand is to be met from the PUWR.

Table 7. Environmental water demand to be met from the potentially utilizable surface flows.

River basin	Potentially utilizable surface water resources[1] (PUSWR)	Non-utilizable surface water resources[2]	Environmental water demand (EWD)	EWD to meet from PUSWR[3]
	BCM	BCM	BCM	BCM
Brahmaputra	22	607	287	0
Cauvery	19	2	4	2
Ganga	250	275	152	0
Godavari	76	34	18	0
Krishna	58	20	14	0
Mahanadi	50	17	12	0
Mahi	3	8	1	0
Narmada	35	11	6	0
Pennar	6	0	1	1
Sabarmati	2	2	0.5	0
Subernarekha	7	6	2	0
Tapi	15	0.4	2	2

Notes: [1] PUWR is from CWC 2004
[2] Non-utilizable water resources – TRWR-PUSWR
[3] The difference between the third and fourth column

The estimated unutilized part of the water resources in many basins is higher than the estimated environmental flow demand. Only three basins—those of Cauvery, Pennar and Tapi—require environmental water demand allocations from the PUWR. However, we caution the interpretation of this result here. The environmental water demand of this paper is estimated at an annual basis, but the flows of Indian rivers vary significantly between months. If the demand is estimated at a monthly basis, the environmental water demand of certain basins could increase, and the PUWR will have to meet part of this demand. As a result, the effective water supply available for other sectors could diminish in many basins.

Sensitivity Analysis

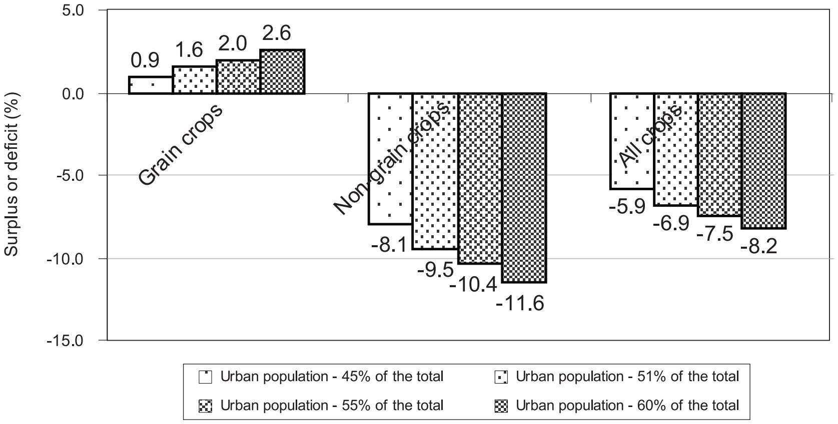
The growth assumptions on many of the drivers under the PODIUMSIM model are sensitive to the final water demand projections. This section assesses the sensitivity of four key drivers—two on the food demand and two on the water demand.

Urban Population Growth

India's urbanization scenarios of different projection studies vary widely. The 2001 census estimates show that most of the urban population projections made earlier have fallen on the higher side than those of the census estimates. Based on this trend Kundu (2006) estimated that the urban population is likely to increase to 45 % of its present total by 2050. The NCIWRD commission assumed an increase of 60 %, and the UN population projections indicate an increase of 50 % in the urban population by 2050 (UN 2004).

Figure 7 shows the sensitivity of future food demand to urbanization. We assume four urbanization scenarios—increases where urban population constitutes 45 %, 51 % (BAU scenario), 50 % and 60% in urban population by 2050. While the food grain demand decreases with increasing urban population, the demand for non-grain crops increases. As a result, the production surplus of grain crops, the production deficit of the non-grain crops, and the production deficit of all crops increase. However, the changes of overall production deficits are not significantly high compared to the urban population growth.

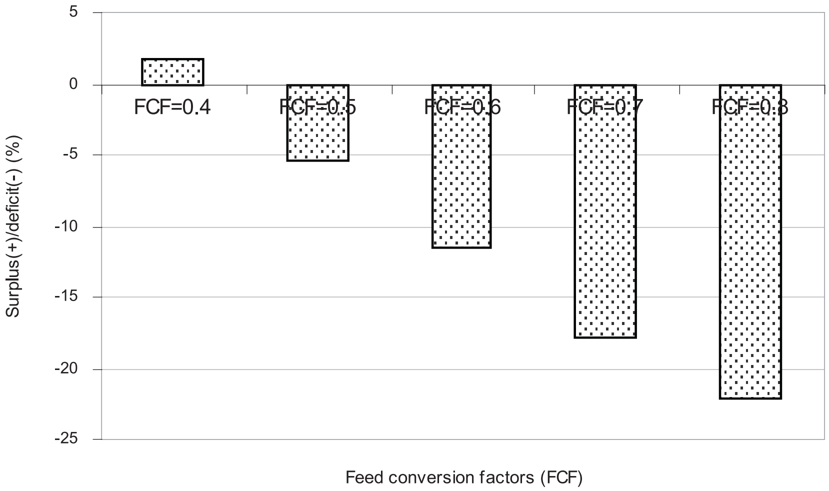
Figure 9. Crop production surpluses or deficits under varying levels of urbanization growth.



Feed Conversion Factor Growth

Figure 8 shows that the feed conversion factor, the quantity of crops used for producing 1,000 kcal of animal products in calorie supply, is an extremely sensitive driver for crop demand projection. As maize is the dominant feed at present, we confine our analysis to grain crops. First, we assume the same level of grain production under the BAU scenario, and then compare it with the demand under different feed conversion factors (FCF). The BAU scenario is that FCF=0.4. If the FCF is double the level of projected by the BAU scenarios for 2050, then the grain deficits would increase to 22 % of the total demand or to about 108 Mmt. Indeed, such a deficit will be a significant burden for a country like India.

Figure 10. Grain production surpluses as a percentage of total demand under different feed conversion factors.



So, could the feed conversion factors in India increase beyond the BAU scenario level? First, we note that feed conversion factors vary significantly between countries, and that they are high in countries where livestock is a commercial industry and stall feeding is common. For example, in the USA, Australia, Brazil and France, food conversion factors are 1.54, 1.06, 0.75 and 0.81 kg/1,000 kcal, respectively.[4] Countries with larger areas of pastureland, such as the UK and New Zealand, have lower feed conversion ratios (0.46 kg/1,000 kcal). In China, the ratio is 0.34 kg/1,000 kcal. However, with a large livestock population, India’s conversion factor in the year 2000 was only 0.11 kg/1,000 kcal. The trends of the last decade show that the land under permanent pastures and the area under fodder are decreasing, and this trend is expected to continue with the increase in nonagricultural income activities (Pandey 1995). Therefore, it is inevitable that the demand for commercial feed would increase.

How will commercial feeding shape up in India in the coming decades? The answer to this depends, first, on the extent to which India can increase its milk productivity in cattle, the extent of animal draught power in agriculture used for labor, and the increase in poultry products in the daily diet. At present, milk is the major calorie provider of animal products, and, in the future, the contribution of poultry products is expected to increase (Amarasinghe et al. 2006). Meat consumption and production, especially beef and pork, in India have been very low due to religious reasons, and this trend will most likely continue in the future too. So, as in the past, much of the cattle and buffalo population in India will be solely utilized for milk production

Among the major milk producers, India has one of the lowest milk productivity; only one-tenth of the milk productivity of the USA, and one fifth of the productivity of New Zealand

---

[4] Feed grain conversion factors of different countries are estimated from the FAOSTAT database (FAO 2005a).

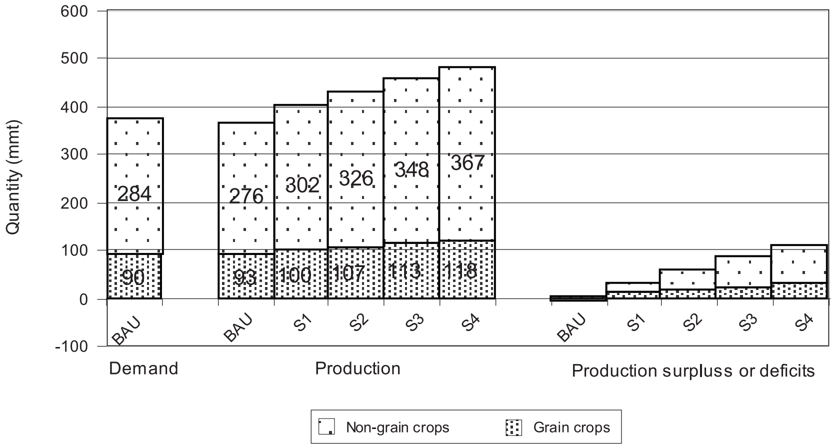
(Hemma et al. 2003). While the USA had a cattle stock of approximately 74 million, India had more than 300 million cattle and buffalos. Indeed, a major part the bovine population in India is non-milk cattle and some are draught animals. Regardless of whether they milk or not, these animals still need feed, fodder or space for grazing.

The demand for pastureland and fodder and also for commercial feeding will depend very much on the number as well as the shape (hybrid, to local) of the cattle population, and how it will increase milk productivity. According to Pandey (1995), while the non-milk cattle population in India has been decreasing, the cross-bred population has been increasing. In spite of these changes, there still exists large scope for improving milk productivity, failing which, India could require a large cattle population for meeting its internal milk demand, and in turn could face a severe shortage in meeting the fodder demand. And this feed shortage will have to be met by commercial feeding.

Crop Yield Growth

The BAU scenario assumed a rather modest growth in crop yield. Thus, under the BAU scenario, the value of overall crop production has a deficit of 4 % of the value of the total crop demand. Figure 9 shows how this deficit changes with higher yield growth. In the alternative scenarios we assumed a slightly higher growth of rain-fed and irrigated yield. While the BAU scenario projects the average grain yield to increase to 3.2 tons/ha by 2050, the four alternative scenarios correspond, respectively, to 3.5, 3.75, 4.0 and 4.2 tons/ha of average grain yield increase by 2050. We assume a similar increase in the growth rates of the non-grain crop yields. In all scenarios we allow for the production deficits in individual crops, and in this paper these mainly include maize, pulses and oil crops. The growth of crop yields in all scenarios, except the last is lower than the growth recorded between 1990 and 2000. In the last scenario we assume the growth to be similar to what was recorded between 1990 and 2000.

Figure 11. Crop production surpluses or deficits under varying levels of yield growth.

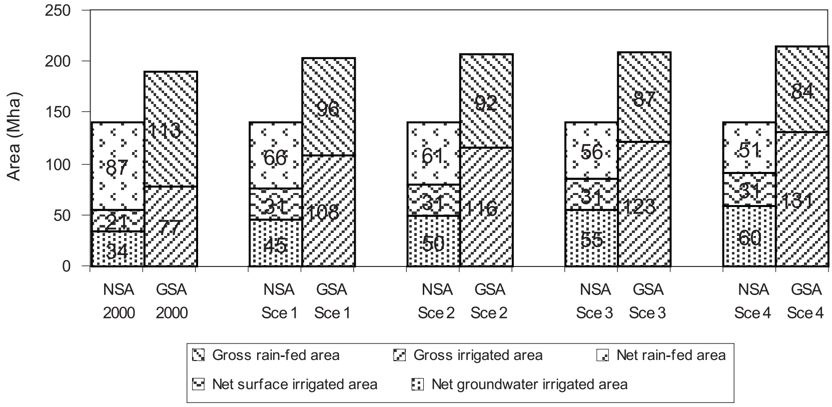


In all the alternative scenarios, both the grain and the non-grain crops record production surpluses. Alternative scenarios, thus, suggest that crop production and the production surpluses can be increased considerably with a slightly higher yield growth.

Groundwater Area Growth

During the last decade, barring the drop in 1999 due to low rainfall, the net groundwater irrigated area increased linearly, adding more than one million hectares every year. And this trend, in spite of little or no growth in canal irrigation, is likely to continue, possibly at a decreasing growth rate. Although the extent of growth is debatable, the impact of groundwater, if it does increase, on the gross irrigated area (GIA) and on the gross crop area (GCA) is very significant. Figure 10 shows the likely growth of GIA and GCA under different net groundwater irrigated area (NGWIA) growth patterns. Scenario 2, the BAU scenario in this paper, assumes that (NGWIA) would increase to 50 Mha. Scenario 1 assumes a slightly lower growth of 43 Mha, while scenarios 3 and 4 assume a slightly higher growth of 55 and 60 Mha, respectively.

Figure 12. Gross irrigated and crop areas under different groundwater development scenarios.



The BAU scenario projects the GIA to expand to 116 Mha. On the other extreme, scenario 4 projects the NGWIA to increase to 60 Mha and as a result the GIA to increase to 131 Mha. The gross groundwater coverage under this scenario could be 86 Mha. Certainly, such a growth is significantly higher than the ultimate groundwater potential of 65 Mha that is projected at present (GOI 1999), and could not be realistic under the present groundwater recharge scenarios.

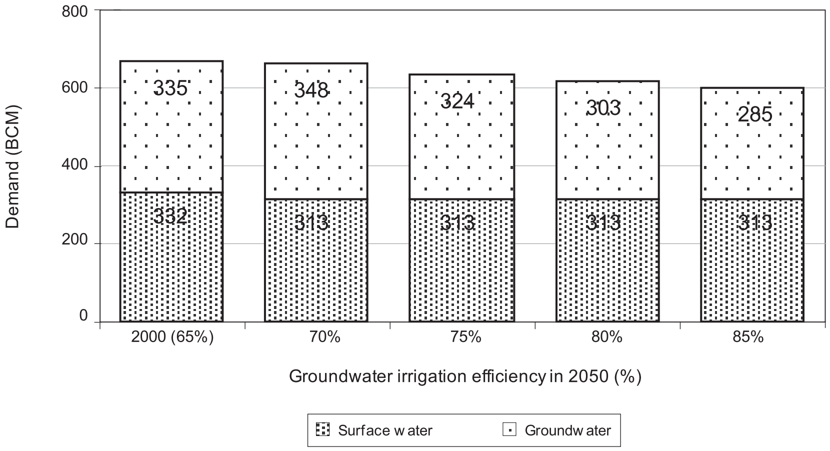
However, if the high groundwater irrigation scenarios are realizable, their impact on crop productivity and crop production growth will be considerable. Studies show that productivity under groundwater irrigation is two to three times higher than the level of productivity under canal irrigation, and, that a small life-saving irrigation of 3 to 5 centimeters of groundwater would considerably increase crop yields over rain-fed yields (Kumar et al. 2006b; Palanisamy et al. 2006, Shah et al 2001).

The higher groundwater irrigation scenarios have a significant impact on water withdrawals too. In general, groundwater irrigation efficiency is 30 % to 50 % higher than canal irrigation efficiency. In 2000, the average water withdrawal for one hectare of canal irrigation was 1.1m, and 0.6 m for one hectare of groundwater irrigation. If the micro irrigation technologies that are commonly used with groundwater irrigation spread, groundwater irrigation efficiency could increase, resulting in a further decrease in groundwater withdrawals. We assess the sensitivity of water demand to irrigation efficiencies in the next section.

Groundwater Irrigation Efficiency

The BAU scenario assumed that groundwater irrigation efficiency would increase from 65 % to 75 % over the next 50 years. Figure 11 shows how water demand decreases with increasing groundwater efficiency.

Figure 13. Irrigation water demand under different groundwater irrigation efficiency scenarios.



The first bar shows the water withdrawals in 2000. The groundwater efficiency in that year was 65 %. The rest of the bars in the graph show the 2050 water demand at varying levels of groundwater efficiency. All the alternative scenarios assume the same surface irrigation efficiency (about 50%), and they show a reduction in the total water demand. If groundwater efficiency can be increased to 80 %, the total water demand could decline by 10 % from its present level.

Can India increase its overall groundwater efficiency to 80 %? The short answer is, it could, but it requires substantial investment in micro irrigation technologies. Recent studies show that groundwater efficiency in many irrigation systems is as high as 85 % to 90 % (Kumar et al.; Palanisamy et al. 2006; Naranyanmoorthy 2006). And, most of these high-performing systems are using water saving technologies at present.

Summary and Policy Implications

This paper projected India’s food and water future in 2025 and 2050 and assessed their sensitivities with respect to key water demand drivers. Trends observed in the last decade were the basis for the assumptions of the key food and water demand drivers, which form the ‘Business-as-Usual’ scenario.

On the water demand and supply, the BAU scenario projects:

- the total water demand to increase from 680 BCM to 833 BCM by 2025, and to 900 BCM by 2050;
- the total water withdrawals as a % of PUWR to increase from 37 % in 2000, to 81 % and 87 % by 2025 and 2050, respectively;
- the degree of development, primary water withdrawals as a % of PUWR, to increase from 37 % to 52 % and 61 % by 2025 and 2050, respectively;
- the industrial and the domestic sectors to account for 54 % and 85 % of the additional demand by 2025 and 2050, respectively;
- groundwater withdrawal to increase from 303 BCM in 2000 to 365 BCM and 423 BCM by 2025 and 2050, respectively, and the groundwater abstraction ratio to increase from 60 % to 74 % and 84 %, respectively.

On the food demand, the BAU scenario projects:

- the non-grain products to provide more than 50 % of the nutritional intake by 2050;
- the feed grain demand to increase rapidly, from a mere 8 Mmt in 2000, to 38 Mmt and 111 Mmt by 2025 ad 2050, respectively;
- the food grain demand to increase slowly, from 178 Mmt in 2000 to 230 Mmt and 241 Mmt in 2025 and 2050, respectively;
- the per capita grain availability to increase from 200 kg/person in 2000, to 210 kg and 238 kg/person in 2025 and 2050, respectively;
- the total grain demand to increase from 201 Mmt in 2000 to 291 Mmt and 377 Mmt by 2025 and 2050, respectively.

On the food supply side, the BAU scenario projects:

- overall production surpluses in grain crops, but substantial imports of maize and pulses, and exports of rice and wheat. The maize import is primarily for livestock feeding. The production deficit of maize is projected to be 22 and 57 Mmt by 2025 and 2050 respectively.
- production deficits in non-grain crops and substantial imports of oil crops (edible oil);

- overall production deficits of all crops to increase from 5 % of the total crop demand in 2000 to 9 % by 2050;
- the gross irrigated area to increase from 76 Mha to 117 Mha during the 2000-2050 period, and the share of groundwater irrigation coverage to increase from 43 Mha to 70 Mha over the same period.

The projections of the BAU scenario are mainly based on the extrapolations of the trends of recent years. Thus, the projections to 2050 are too far ahead, and there is every possibility that the unexpected changes in demand drivers could significantly alter the BAU demand directions. We selected a few water demand drivers that could change sharply and bring in these unexpected changes in the projection. At the same time, proper policies could offer significant opportunities to lessen the variability of the demand drivers or the impacts of the changes.

The urban population could increase at a much higher rate than the assumed level in BAU, but this will not significantly impact food production surpluses, although it can have a considerable impact on the domestic water demand. The investments required to increase the domestic water supply coverage could drastically change under such a scenario. If the urban population increases to 60 % of the total population by 2050, as against 51 % in the BAU scenario, the total domestic water demand could increase from 101 BCM to 107 BCM.

Increasing feed deficits with higher feed conversion ratios is also a concern. If the feed conversion ratio doubles, then the feed grain deficits will be more than double. As we have discussed earlier, there is ample scope for reducing the feed demand by improving milk productivity. A combination of investments in extension and research, introduction of hybrid highly-productive livestock, control of the unproductive cattle population growth, etc., could help reduce the demand for commercial feed. In the absence of these, feed deficits can increase more than 100 Mmt. Meeting such huge feed deficits consistently via international trade could also be problematic for a country like India.

Crop productivity growth offers the best solution for meeting the increasing demand for food and feed, and increasing the income of the rural poor. The sensitivity analysis in this paper suggests that the crop yield of 0.5 % over and above the BAU scenario could propel crop production to significantly higher levels. And the investments in research and extension, and revising the policies for pro-productivity growth could offer a way out of the predicament that India is in, at present, in terms of the declining crop yield growth.

Groundwater irrigation expansion is a key driver of agricultural production and water demand growth. Water demand projection of the BAU depends very much on the extent of net groundwater area expansion. Investment in small-scale structures that can enhance groundwater recharge in locations where there are no adverse impacts on downstream users, and abstraction of groundwater in areas where it is abundantly available, are a few other policy options.

As groundwater will be the dominant source of irrigation in the future, micro irrigation technologies could offer significant opportunities for increasing efficiency in water use, and thereby reduce over abstraction. Indeed the BAU scenario assumes a significant growth in groundwater efficiency. Spreading water saving technologies through investment promotions could be the key here.

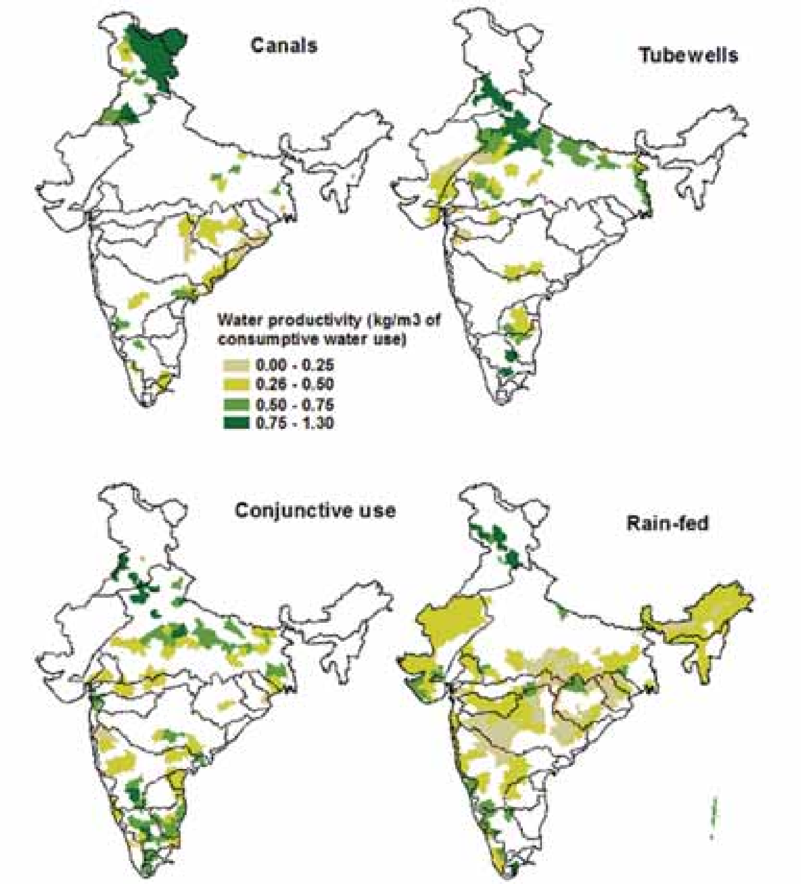
The BAU scenario projections are not overly pessimistic, but, they still call for substantial investments for meeting future water demand. Growth of the agriculture sector water demand would mainly depend on groundwater development and efficiency enhancements, which requires investments in increasing groundwater recharge, spreading water saving technologies, and enhancing efficiency and crop productivity. However, a major part of the additional water demand in the industrial and domestic sectors of the BAU scenario would have to be met from surface water supply. By 2050, the BAU scenario estimates 117 BCM as the additional water requirement for the two sectors. This growth is equivalent to 20 BCM every decade over the next 50 years. The BAU scenario projects that a part of this requirement is to be met from the excess surface irrigation supply, but it still requires adding new water supplies, equivalent to or more than the water in the Aswan Dam. Does this mean large-scale water transfers between basins would be needed? The answer to this could be yes, and the large-scale water transfers could only be justifiable on the ground that the burgeoning industrial sector could demand, and is willing, to pay for a more reliable surface water supply for their production processes. But, the extent of these water transfers depends on the extent to which India can improve its crop water productivity.

By how much can India increase her crop water productivity over the next 50 years? At the moment we don’t know the answer to this question, but we do know, as seen in the concluding discussion of this paper, that improving water productivity will have a significant impact on future water needs. Amarasinghe et al. (2006) showed that a modest increase (1% annually) in water productivity (quantity per consumptive water use) could eliminate the additional consumptive water demand for grains. And, with a 1.3 % annual increase it could eliminate the consumptive water demand of all crops. India’s crop water productivity is very low at present and varies widely across regions. Figure 12 shows these variations across districts dominated by surface irrigation, groundwater irrigation, conjunctive irrigation and rain-fed irrigation.[5] This shows that the crop productivity of many districts is well below the average crop water productivity, and that there is substantial scope for increasing water productivity in all crops, be they grain and or other. If this increase can be realized, the water requirement of the other sectors can be met by existing water resources.

---

[5] Rain-fed-dominated districts are those with a gross irrigated area (GIA) less than 25 % of the gross crop area. Of the remaining districts, canal-irrigation dominated ones are those with a gross canal irrigated area greater than 50 % of the GIA. Tubewell-dominated districts are those with a gross tubewell-irrigated area greater than 50 % of the GIA. The remaining districts are classified as those having a conjunctive use.

Figure 14. Water productivity of grain crops in districts dominated by canal, tubewell and conjuctive irrigation and rain-fed agriculture.



Annex 1

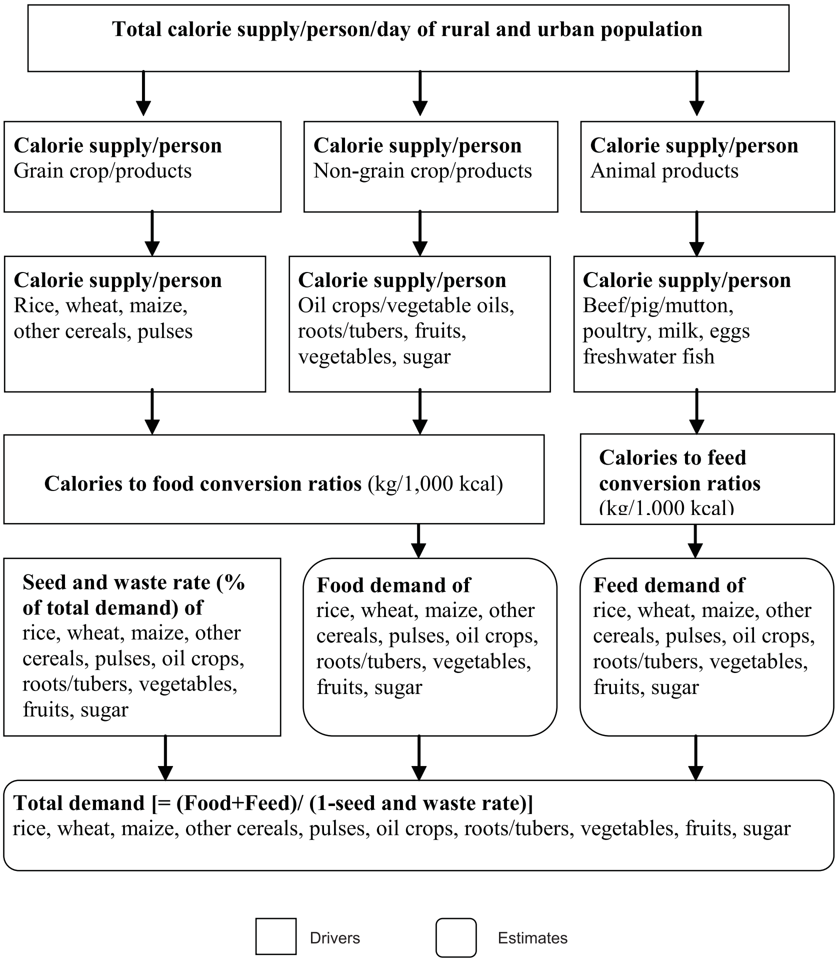
PODIUMSIM Components

The four major components of the PODIUMSIM (the policy dialogue model used for simulating scenarios) are briefly presented here. For more details, please refer to www.iwmi.org/applications/podium.

Crop Demand

The crop demand module estimates the total demand of 11 crop categories. The total demand includes the demand for food, feed and seeds and other uses. And the crops include rice (milled equivalent), wheat, maize, other coarse cereals, pulses, oil crops (including vegetable oils), roots and tubers, vegetables, fruits, sugar and cotton. The crop demand component is given in Annex 1, Figure 1.

Annex 1, Figure 1. Flow chart: Crop demand estimation module.

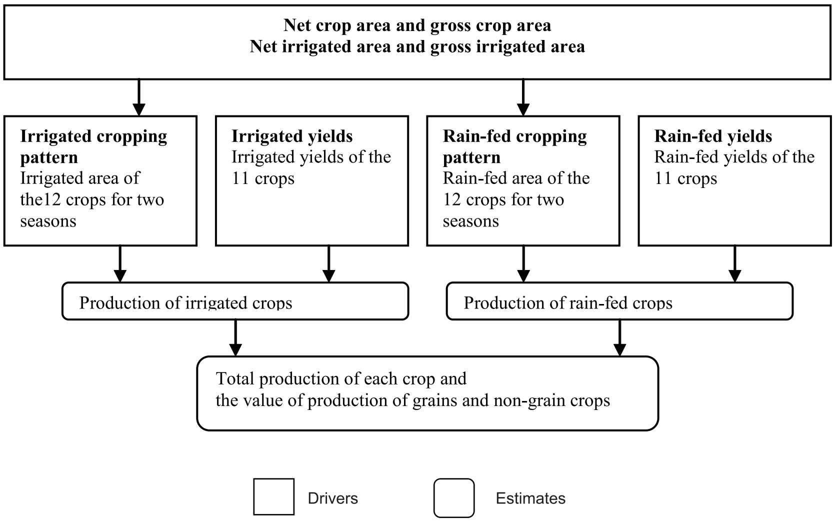


The primary objective of crop demand components is to estimate the crop requirement to achieve a certain nutritional level for the population. First, the model sets the level of daily nutritional intake per person for the urban and the rural sectors. Second, the composition of the calorie supply from grain products, non-grain crop products and animal products of the rural and the urban sectors is determined. The next step is to estimate the food and feed requirements. The food demand of different crops is obtained by multiplying the calorie intake by the food conversion factors. The food conversion factor is the quantity (kg) of food required to generate 1,000 kcal of calorie supply. The feed demand is estimated by multiplying the feed conversion ratios with the animal products' calorie supply. The feed conversion ratio is defined as the quantity (kg) of a crop used for generating 1,000 kcal of animal products in the diet. The final step is to estimate the quantity of crop allocated for seeds, waste and other uses. This is given in the model as the ratio of seed and waste to the total crop requirement. In conclusion, the total food and feed demand, and ratio of seed and waste are used to estimate the total crop demand.

Crop Production

The crop production module estimates the irrigated and rain-fed crop production of the 11 crop categories at the subnational level (Annex 1, Figure 2). The unit of analysis can be a river basin or an administrative unit. First, the model determined the net and gross sown and irrigated area of each unit. Next, the cropping patterns of the 11 crop categories and their crop yield growth are specified. Besides the 11 crops in the crop demand module, the specified irrigated cropping patterns include fodder and other irrigated crops. The model estimates the crop production for the 11 crop categories and the value of production for grain and non-grain crops. The value of production is based on the average export prices of the base year of the model (in this paper the average export prices are those of 1999, 2000 and 2001).

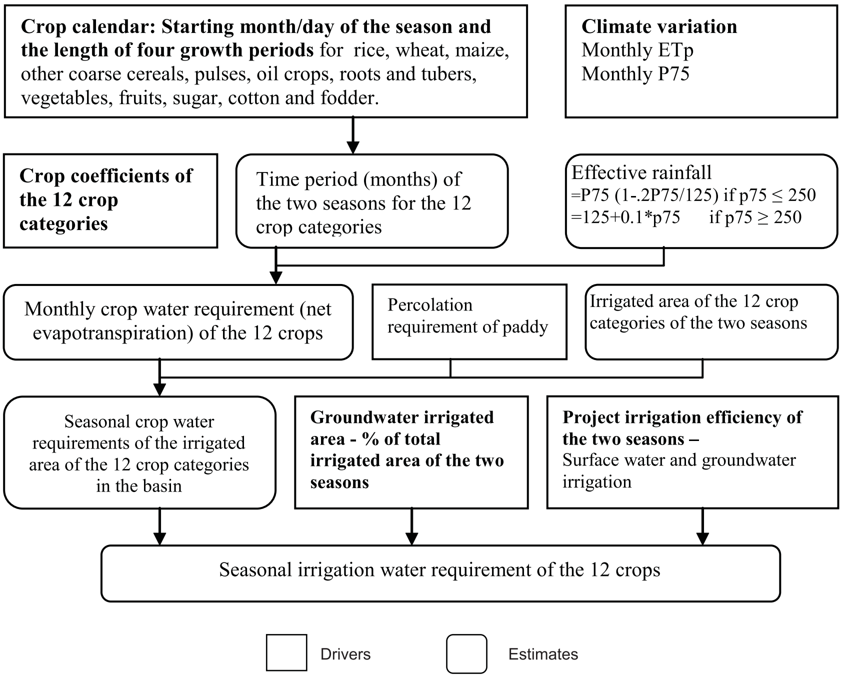
Annex1, Figure 2. Flow chart: Crop production estimation module.



Irrigation Water Demand

The PODIUMSIM model estimates the monthly irrigation water requirements during cropping periods for different seasons (Annex 1, Figure 3). First, the model specifies the months of the crop growth periods using the starting date (month and day) of the season and the length of the growth periods. Next, it estimates the crop water requirement for each growth period using effective rainfall, Potential evapotranspiration (Etp) and crop coefficients. Seasonal irrigation water demand is determined using the estimates of the crop water requirements, the extent of groundwater irrigated area in the basins, and the project irrigation efficiencies of surface water and groundwater irrigation (see www.iwmi.org/applications/podium for more details).

Annex1, Figure 3. Flow chart for irrigation water demand estimation.



Domestic and Industrial Water Demand

The domestic water demand includes the human and livestock water demands. The human water demand is based on the norms of 150 liters per capita per day (lpcd) in the rural areas and 200 lpcd in the urban areas. The livestock water demand is based on the cattle and buffalo population and uses the norm of 25 liters per day per head water demand. The growth of industrial water requirement is taken as the driver for estimating the industrial water demand.

Environmental Water Demand

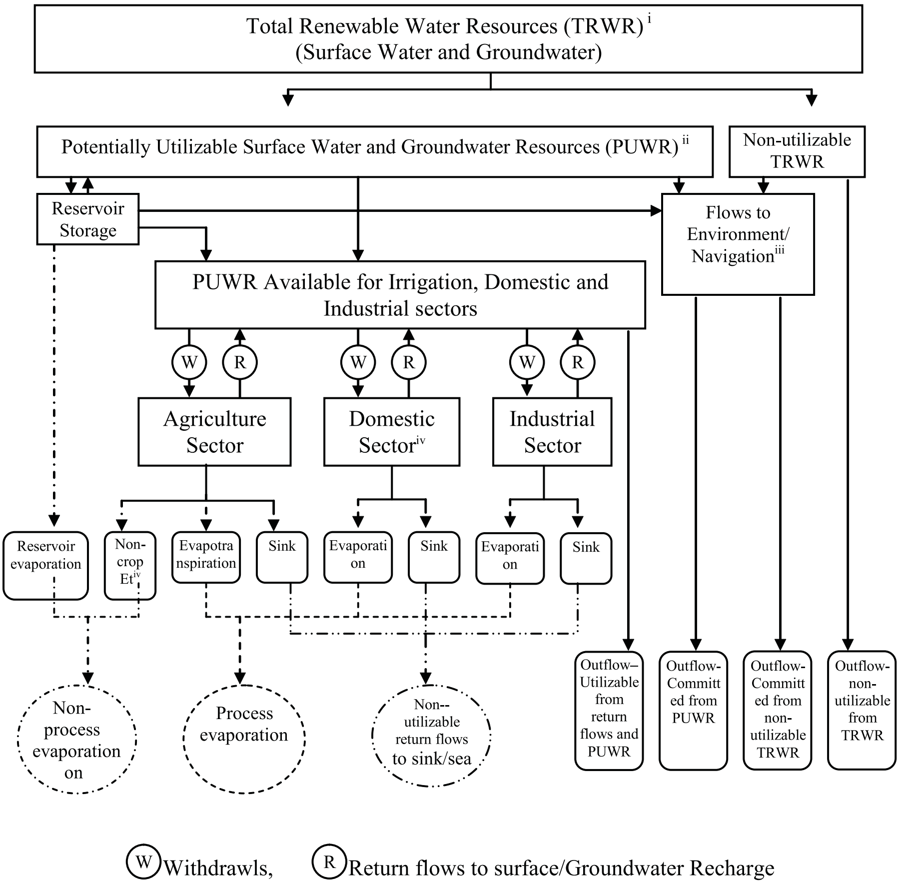
The environmental water demand component estimates the part of minimum flow requirement (MFR) of a river that has to be met from the potentially utilizable water resources (PUWR). First, we observe only a part of the minimum flow requirement in each month can be met from the non-utilizable part of the total renewable surface water resources (RSWR) or mean runoff. From this we estimate the minimum flow requirement that cannot be met from non-utilizable IRWR, and has to be met from the PUWR. Ideally, this portion of the MFR should not be made available for other users in the basin. But in most river basins, this cannot be implemented due to the increasing pressure from other sectors. Therefore, the model keeps this portion of the PUWR as a driver for determining the future environmental flow requirement scenarios.

Accounting of Utilizable Water Resources

The PODIUMSIM model estimates water accounts of the potentially utilizable water resources of a river basin (Annex 1, Figure 4). At any given time, only a part of the potentially utilizable water resources is developed and is used by the different sectors. Of the water diversions to the agricultural, domestic and industrial sectors, the model estimates:

- Process evaporation (evapotranspiration in the irrigation sector and consumptive use in the domestic and industrial sectors);
- Balance flows, i.e., the difference between the withdrawals and the process evaporation;
- Return flows to surface water supply and recharge to groundwater supply;
- Non-process evaporation, i.e., flows to swamps in irrigation;
- Non-utilizable flows to the sea or a sink; and
- Utilizable flows to the sea from the surface water return flows and groundwater recharge.

Annex 1, Figure 4. Flow diagram of water accounting.



i. TRWR – Total renewable water resources

ii. PUWR – Potentially utilizable water resources

iii. Parts of the environment and navigation flows are met from non-utilizable TRWR and the other parts are met by PUWR

iv. Domestic sector includes livestock sector water needs

The three indicators of the extent of water development in the basin: the degree of development, the depletion fraction and the groundwater abstraction ratio are given by

$$Degree\ of\ \ development = \frac{primary\ water \sup ply}{PUWR - environmental\ \ flows\ \ from\ PUWR}$$

$$Depletion\ \ fraction = \frac{total\ depletion}{primary\ water \sup pply}$$

$$Groundwater\ abstraction\ ratio = \frac{Total\ ground\ water\ withdrawals}{Total\ available\ groundwater \sup ply}$$

where, the primary water supply is defined as

$$\begin{aligned} \Pr imary\ water \sup ply = \Pr ocess\ evaporation + non\ \ process\ evaporation + \\ un\ utilizable\ \ flows\ to\ sea + utilizable\ returnflows\ to\ sea \end{aligned}$$ and

the total depletion of the primary water supply is

$$\begin{aligned} Total\ depletion = \Pr ocess\ evaporation + non\ \ process\ evaporation + \\ + un\ utilizable\ \ flows\ to\ sea \end{aligned}$$

References

Agarwal, P.K.; Talukdar, K.K.; Mall R.K. 2000. *Potential yields of rice-wheat systems in the Indo-Gangetic plains of India.* Rice-Wheat Consortium Paper Series 10. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Allan, J.A. 1998. Virtual water: Strategic resources. global solutions to regional deficits. *Groundwater* 36: 545-546.

Amarasinghe, U.A.; Sharma, B.R.; Aloysius, N.; Scott, C.; Smakhtin, V.; de Fraiture, C. 2005. *Spatial variation of water supply and demand across river basins of India.* Research Report 83. Colombo, Sri Lanka: International Water Management Institute.

Amarasinghe, U. A.; Shah, T.; Singh, O. 2006. Changing consumption patterns: Implications for food and water demand in India. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Bhaduri, A.; Amarasinghe, U.A.; Shah, T. 2006. *Groundwater irrigation India: Ananlysis and prognostics.* Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Bhalla, G. S.; Hazell, P.; Kerr, J. 1999. *Prospects of India's cereal supply and demand to 2020.* Food, Agriculture and the Environment Discussion Paper 29. Washington, D.C., USA: International Food Policy Research Institute (IFPRI).

CWC (Central Water Commission). 2004. *Water and related statistics.* New Delhi, India: Water Planning and Projects Wing, Central Water Commission.

de Fraiture, C.; Molden D.; Rosegrant, M.; Cai, X.; Amarasinghe, U. 2004. *Does international cereal trade save water? The Impact of Virtual Water Trade on Global Water Use*. Comprehensive Assessment Research Report No 5. Colombo, Sri Lanka: International Water Management Institute.

Dyson, T.; Hanchate, A. 2000. India’s demographic and food prospects: State level analysis. *Economic and Political Weekly* 11: 4021-4036 (November).

FAI (Fertilizer Association of India). 2003a. *Fertilizer and agriculture statistics, northern region 2002-2003.* New Delhi, India: The Fertilizer Association of India.

FAI. 2003b. *Fertilizer and agriculture statistics, western region 2002-2003.* Mumbai, India: The Fertilizer Association of India.

FAI. 2003c. *Fertilizer and agriculture statistics, eastern region 2002-2003*. New Delhi, India: The Fertilizer Association of India.

FAI. 2003d. *Fertilizer and agriculture statistics, southern region 2002-2003.* New Delhi, India: The Fertilizer Association of India.

Falkenmark, M.; Lundqvist, J.; Widstrand, C. 1989. Macro-scale water scarcity requires micro-scale approaches: Aspect of vulnerability in semi-arid development. *Natural Resources Forum* 13 (4): 258-267.

FAO (Food and Agriculture Organization). 1998. *Crop evaporation guidelines for computing crop water requirements.* FAO Irrigation and Drainage Paper No. 56. Rome, Italy: Food and Agriculture Organization.

FAO. 2003. *Review of world water resources by country.* Water Reports No. 23. Rome, Italy: Food and Agriculture Organization.

FAO. 2005a *FAOSATAT data base.* Rome, Italy: Food and Agriculture Organization

FAO. 2005b. *AQUASTAT data base.* Rome, Italy: Food and Agriculture Organization.

Gardener-Outlaw, T.; Engleman, R. 1997. *Sustaining Water, Erasing Scarcity. A Second Update.* Washington, D.C., USA: Population Action International.

GOI (Government of India) 1999. *Integrated water resources development. A plan for action.* Report of the Commission for Integrated Water Resource Development Volume I. New Delhi, India: Ministry of Water Resources.

GOI. 1996. *Key results on households consumer expenditure in 1993-94, 50th round.* Report No. 401. New Delhi, India: National Sample Survey Organization, Ministry of Statistics, Government of India.

GOI. 2002. *Consolidated results of crop estimation survey on principal crops 2001-2002.* New Delhi, India: National Sample Survey Organization, Ministry of Statistics, Government of India.

GOI (Government of India) 2003. *Final Population Totals – India (India, State, District, Sub-district, Town, Ward-in-town & Village).* New Delhi, India: Office of the Registrar General & Census Commissioner, India.

GOI. 2004. *Agricultural statistics at a glance 2004.* New Delhi, India: Ministry of Agriculture, Government of India.

Hargraves, G. H.; Samani, Z. A. 1986. *World water for agriculture.* Logon, Utah, USA: International Irrigation Center, Department of Agricultural and Irrigation Engineering, Utah State University.

Hemme, T. Garcia, O.; Saha, A. 2003. *Review of milk production in with a particular emphasis on small-scale producers*. PPLPI Working Paper No. 2. Rome, Italy: FAO.

INCID (Indian Committee on Irrigation and Drainage) 1998. *Sprinkler irrigation in India.* New Delhi, India: Indian Committee on Irrigation and Drainage.

IWMI (International Water Management Institute). 2000. *World water supply and demand 1995 to 2025 (draft)*. www.cgiar.org/iwmi/pubs/WWVison/WWSDOpen.htm

IWMI. 2001. *IWMI climate and water atlas.* Colombo, Sri Lanka: IWMI CD-ROM.

IWMI. 2005. *Land use land cover (LUCL-MODIS 500m, 2000),* www.iwmidsp.org

Joshi, P.K.; Birthal, P.S.; Minot, N. 2006. *Sources of agriculture growth in India. Role of diversification towards high-value crops.* MTID Discussion Paper No. 98. Washington, D.C., USA: International Food Policy Research Institute.

Kumar, D.; Singh, O.P. 2005. *Virtual water in global food and water policy making: Is there a need for rethinking?* IWMI-Tata Water Policy Research Highlights,

Kumar, M.D.; Samad, M.; Amarasinghe, U.A.; Singh, O.P. 2006. Water saving technologies: How far can they contribute to water productivity enhancement in Indian agriculture? Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Kumar, M.D.; Singhe, O.P.; Samad, M.; Purihit, C.; Didyla, D. 2006. Water productivity of irrigated agriculture in India. Potential areas of improvement. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Kundu, A. 2006. Estimating urban population and its size class distribution at regional level in the context of demand for water: Methodological issues. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Mahmood, A.; Kundu, A. 2006. Demographic projections for India 2006-2051: Regional variations. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Molden, D.J. 1997. *Accounting for water use and productivity.* SWIM Paper 1. Colombo, Sri Lanka: International Water Management Institute.

Narayanamoorthy, A. 2006. Potential for drip and sprinkler irrigation in India. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

NSSO (National Sample Survey Organization). 2001. *Key results on households consumer expenditure in 1999-2000 55th round.* Report No. 461. New Delhi, India: Department of Statistics, Government of India.

Palanisami, K.P.; Senthivel, K.; Ranganathan, C.R.; Ramesh, T. 2006. Water productivity at different scales under canal, tank and tubewell irrigation systems. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Pandey, U.K. 1995. The Livestock Economy of India: A Profile. *Journal of Indian Agricultural Economics.* 50. (3): 264-282.

Rao, H.C.H. 2005. *Agriculture, food security, poverty and environment.* New Delhi, India: Oxford University Press.

Rosegrant, M. W.; Paisner, M.S.; Meger, S.; Witcover, J. 2001. *Global food projections to 2020.* Washington, D.C., USA: International Food Policy Research Institute.

Rosegrant, M.W.; Cai, X.; Cline, S.A. 2002. *World water and food 2025. Dealing with scarcity.* Washington, D.C., USA: International Food Policy Research Institute.

Rijsberman, F.R. 2000. *World water scenarios: Analysis.* London, UK: Earthscan Publications.

Seckler, D.; Amarasinghe, U.A.; Molden, D.; de Silva, R.; Barker, R. 1998. *World water demand and supply 1995 to 2025: Scenarios and issues.* Research Report No. 19. Colombo, Sri Lanka: International Water Management Institute.

Shah, T.; Roy, A.D.; Qureshi, A.S.; Wang, J. 2001. Sustaining Asia's groundwater boom: An overview of issues and evidence. Draft paper prepared for the International Conference on Freshwater in Bonn.

Sharma, B. 2006. The 'tipping point' in Indian agriculture. Understanding the withdrawal of Indian rural youth. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Sharma, B.; Rao, K.V.; Vittal, K.P.R. 2006. Realizing the rain-fed agriculture potential in India. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Smakhtin, V.; Anputhas, M. 2006. *An assessment of environmental flow requirements of Indian river basins.* Research Report 107. Colombo, Sri Lanka: International Water Management Institute.

UN (The United Nations). 2004. *World population prospects, the 2004 revision.* New York, USA: UN Department for Policy Coordination and Sustainable Development.

WRI (World Resources Institute). 2005. *Earth trends*. Searchable database http://earthtrends.wri.org. Washington, D.C.

Analysis of the Inter-basin Water Transfer Scheme in India: A Case Study of the Godavari–Krishna Link

Luna Bharati[1]*, B.K. Anand*[2]*, and Vladmir Smakhtin*[1]
[1] *International Water Management Institute, Sri Lanka*
[2] *Consultant, Bangalore*

Introduction

The National River Linking Plan (NRLP) was designed to alleviate emerging water scarcity problems in India. Transfers of 'surplus' water from primarily Himalayan rivers to more 'deficient' peninsular rivers have been predicted to reduce imbalances in water availability in the country. The Himalayan component intends to transfer 33 km^3 and the peninsular component 141 km^3 of water through the combined network of 30 links, amounting to a total length of 14,900 km (GOI 1999). The proposed plan, if fully completed, will be the largest ever infrastructure project in the world, costing an estimated 120 Billion US Dollars. The additional benefits claimed by the NRLP include, flood control, drought mitigation, increased irrigation, additional food-grain production and electricity generation. The NRLP, however, remains a controversial issue in India. This is partially due to the non-transparent and, largely, uni-sectoral nature of water resources planning, which places the major focus on irrigation development, as well as a lack of confidence in the characterization of particular river basins as either 'surplus' or 'deficient'.

The main objective of this present study is to independently evaluate the water availability as against the water demand in one of the NRLP links i.e., from the Godavari River (at Polavaram) to the Krishna River (at Vijayawada). This transfer is further referred to in the paper as the 'Polavaram Project'. The Godavari has been characterized as a 'surplus' basin whereas the Krishna Basin as a 'deficit' one (GOI 1999). In Indian engineering practice, 'surplus basins' are defined as those which have a positive balance: i) of 75 % assured annual river flow volume; and ii) in the total annual volume of all water demands, projected up to the year 2050. Basins which have a negative balance of the above two components are classified as 'water deficient'. The analysis to characterize the rivers is done using annual flows (GOI 1999). Smakhtin et al. 2007 have argued however, that this planning process adopted by the Indian Government has ignored the seasonal variability of flow within a year, which is extremely high in monsoon-driven Indian rivers. As a result, much more water is perceived to be originally available at a site of transfer than is the actual case. This paper attempts to examine whether the planned water transfers will satisfy the growing water demands in the Polavaram link command area as well as identify the link's impacts outside of the command area, and uses the

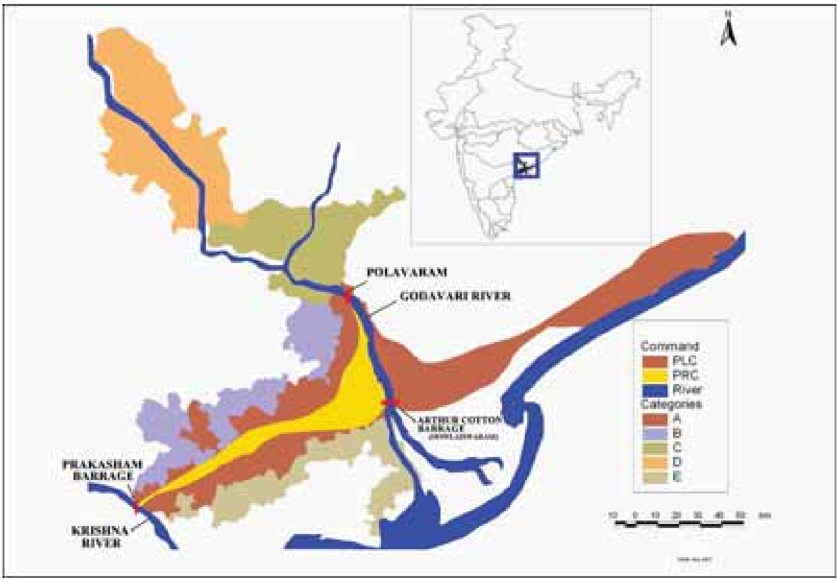
Water Evaluation and Planning Model Version 21 (WEAP 21) for this exercise. Further, in order to examine the effects of seasonal variability, the analysis is done at a monthly time step. The main reason for selecting this particular link is because the Polavaram Project is to be implemented in the near future, regardless of other NRLP water transfers.

Godavari - Krishna Water Transfer and the Polavaram Project

The Godavari River is the second largest river in India with a catchment area of 312,812 km^2 and a long-term average annual surface flow of 110 km^3, of which 76 km^3 is estimated as non-utilizable (NCIWRD 1999). The cultivable area in the basin is about 18.9 million ha. There are already two major diversion structures in the basin. The Sri Ram Sagar Project (upstream of Polavaram) and the Arthur Cotton Barrage (downstream of Polavaram) provide irrigation water to 390,000 ha and 170,000 ha, respectively, in the Lower Godavari Basin. Similar to other parts of India, the use of groundwater to meet irrigation water demands is also a common practice in the Basin. Based on annual water balance calculations as well as the current and projected (for 2025) water requirements, the Central Water Commission (CWC) has concluded that the Godavari Basin has sizeable surpluses that can be transferred to the water-deficit Krishna Basin.

The Krishna River basin is the fourth largest in India with a total catchment area of 258,948 km^2 and a long-term average annual surface flow of 78 km^3, of which 58.0 km^3 is considered to be utilizable (Amarasinghe et al. 2005). The cultivable area in the basin is about 20.3 million ha.

Figure 1. A schematic map of the proposed Polavaram Project. PLC and PRC- the Polavaram left and right bank command areas, respectively.



Note: Category A = the command area for the link canal; Category B = mandals upstream of the link command area; Category C = the area submerged by the proposed reservoir; Category D = mandals upstream of the proposed Polavaram Reservoir; and Category E = the mandals downstream of the link canal command area. Locations A and C will be directly affected by the project. Locations B, D, and E will be indirectly affected by the project

Three large irrigation projects are operational in the basin. The Krishna Delta Project near Vijayawada, which is expected to directly benefit from the Polavaram water transfer, was constructed in 1852 (Figure 1), and was designed to irrigate 530,000 ha of land. The Krishna Delta plays a vital role in the rice economy of the nation and in addition to the major dam, a large number of informal irrigation sources such as groundwater tubewells, tanks and minor reservoirs are spread throughout the area. Due to the massive surface irrigation development and the rapid expansion of groundwater irrigation, the annual river flow at the Krishna outlet has decreased to approximately 36 % of its pre-development level, and certain studies have reported on the 'closure' of the basin (e.g., Biggs 2005).

Several links have been proposed to transfer water from the Godavari to Krishna. Some of them are planned as parts of much longer transfers from the Himalaya to the peninsula. The most 'downstream' link – Polavaram (Godavari River) -Vijayawada (Krishna River) (Figure 1) – can, however, be seen as a 'local' project because the main aim of this link is to transfer, to an already water-deficient and over-utilized Krishna Delta, what is perceived as 'surplus' water from the more water-endowed Godavari River. Furthermore, the project is expected to reduce informal irrigation and the use of groundwater in the Krishna Basin.

The Polavaram Project

The climate in the command area of the Polavaram Project (Figure 1) varies from hot, semi-arid to sub-humid, to tropical. The monsoon season (known as kharif in India) extends from June to October, and the post-monsoon season (rabi) - from November to March with a usual annual dry spell during April to May. Average annual rainfall is 1,000 mm, with over 80 % falling during kharif due to southwest monsoons. The temperature varies from 44 ^{0}C in May to 22 ^{0}C in December. The overall population density in the command area is 543 persons per km^2 with 60 % of the population being dependent on agriculture (GoAP 2003).

Figure 1 shows the proposed project including the site of the Polavaram Reservoir and the command area of the link canal. The project includes two canals, i.e., one on the right and one on the left bank of the Godawari River. The Polavaram –Vijayawada link command area is located on the right bank, with the link canal starting from the proposed Polavaram Reservoir. The left main canal will transfer 3,663 MCM (million cubic meters) for irrigation and industrial needs. The link canal on the right bank will divert 5,325 MCM for irrigation, domestic supply and industrial use. The planned Polavaram Dam is to have a live storage of 2,130 MCM. The annual total water use is, however, estimated to be 8,000 MCM. Since the planned storage is small in comparison to the water use, run-of–the–river flows will be utilized to ensure the expected benefits of the project. Thus the project will function more as a barrage combined with limited storage use. The project also includes a hydropower component (GOI 1999). It has been estimated that the proposed reservoir will submerge around 63,000 ha of land, which at present hosts 250 villages with a total population of 145,000 (Census 1991; GOI 1999; GOI 2006).

The government feasibility report states that the total cultivable area of the Polavaram link canal is 139,740 ha. Of this area, 71 % (99,755 ha) is irrigated by bore wells, tanks and open head channels taking off from the river, and the balance 29 % (39,985 ha) is non-irrigated

(GOI 1999). An independent survey conducted by Bhaduri et al. (2007) in the Polavaram area to assess the irrigation benefits, showed that these figures are outdated and that 95 % of the cultivated area in the link command area is under irrigation at present. Table 1 shows the different sources of irrigation in the link command area. Bhaduri et al. (2007) indicate that all cultivable area is irrigated and the remaining 5 % that is not irrigated is not under cultivation. Therefore, the assumption that 39,985 ha of new irrigated area will develop due to the link canal is overestimated, as the existing Sir Arthur Cotton Barrage in the Godavari, the Prakasham Barrage in the Krishna, and lift irrigation from the main river channel, all supply surface water to the Deltas. Therefore, most of the 'new area', which according to the feasibility study is to be brought under irrigation, already is being irrigated with groundwater and water from either tanks or canals. Table 1 shows that currently 84 % of the command area is irrigated with groundwater and 9 % by canals (Bhaduri et al. 2007).

Table.1 Source of water as percentage of total irrigated area in the Polavaram link area.

Source	Right Bank Location 1 (C,D)	Right Bank Location 2 (E)	Right Bank Location 3 (A)	Right Bank Location 4 (B)	Left Bank Location 3 (PLC)	Left Bank Location 4
Canal	0	100	9	41	20	50
Conjunctive use	0	0	0	1	0	0
Groundwater	97	0	84	50	64	46
Pump irrigation	0	0	0	5	0	2
Rain-fed	2	0	7	0	0	2
Tank	1	0	0	2	16	0

Source: Survey (Bhaduri et.al. 2007)

Note: The letters in brackets correspond to locations in Figure 1
Location of the link: 1= Upstream of the proposed Polavaram Reservoir including the submergence area, 2 = Downstream of the Polavaram Project area, 3= Command area of the link canal, 4 = Outside the command area of the link canal.

Once the link is built, it is proposed that paddy, sugarcane, chilies and pulses should be planted - considering the soil suitability, agro-climatic conditions and local practices (GOI 1999). Furthermore, irrigated crop intensity, which is the ratio between irrigated crop areas (where double or triple cropping areas are counted twice or three times, respectively,) and the physical areas equipped for irrigation, is expected to reach 150 %. The current existing cropping pattern in the command area is dominated by paddy, sugarcane and tobacco during both the kharif and rabi seasons (Bhaduri et al. 2007). Increased upstream development, especially through the construction of reservoirs and irrigation systems in the Krishna, has resulted in a decline in downstream flows, which has affected the cropping patterns in the Krishna Delta. When enough water is available, usually two rice crops are grown per year, but in the Krishna it has been observed that during dry years, only one rice crop is grown with another less water intense crop being grown during the rabi season (Dr. Chandrashekhar Biradar, IWMI, pers. Comm.). In the Godavari Delta on the other hand, two paddy crops are grown but only with supplemental groundwater use.

Methods

Summary of the WEAP 21 Model

The Water Evaluation and Planning Model (WEAP), developed by the Stockholm Environmental Institute (SEI), is designed to evaluate scenarios of water resources development and changes in the bio-physical and socioeconomic conditions of catchments over time (Yates et al. 2005). One of WEAP 21's strengths is that it places the demand side of the water balance equation on par with the supply side. In WEAP, water supply is defined by the amount of precipitation that falls on a catchment or a group of catchments. This supply is progressively depleted through natural processes, human demands and interventions, or enhanced through accumulations/storages. Thus, WEAP 21 adopts a broad definition of water demand, where the catchment itself is the first point of depletion through evapotranspiration. The core of the model is a water balance equation that includes components such as catchment-scale evaporation demands, rainfall-runoff processes, groundwater recharge and irrigation requirements. These are linked to the stream network and water allocation components (demand sites) via the WEAP 21 interface, where a stream network keeps track of water allocations and accounts for streamflow depletion and addition (Yates et.al. 2005). The model optimizes water use in a catchment using an iterative linear programming algorithm, the objective of which is to maximize the water delivered to demand sites, according to a set of user-defined priorities. All demand sites are assigned a priority between 1 and 99, where 1 is the highest priority and 99 is the lowest. When water is limited, the model progressively restricts water allocation to demand sites with lower priority. More details of the model are available in Yates. et al. (2007) and SEI (2001).

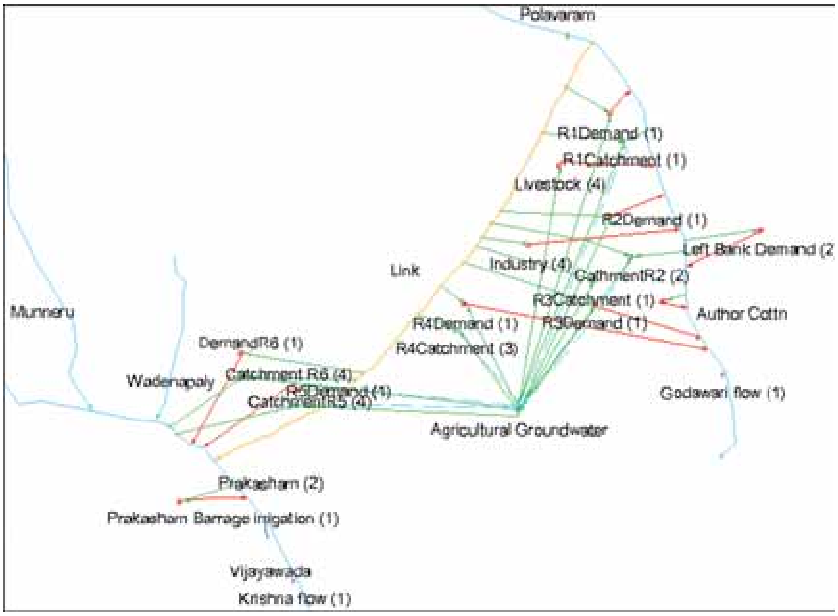
Scenario Formulation

In order to assess the benefits of the proposed Polavaram Project, two main scenarios were developed and simulated.

- *Scenario 1 – Reference Scenario:* water use under the current supply and demand network. The water sources are groundwater and the river channel.
- *Scenario 2 – With the Polavaram Reservoir and link canal*: water supply versus demand after the construction of the Polavaram Project. The water sources are the Polavaram Reservoir and link canal, groundwater and the river channel.

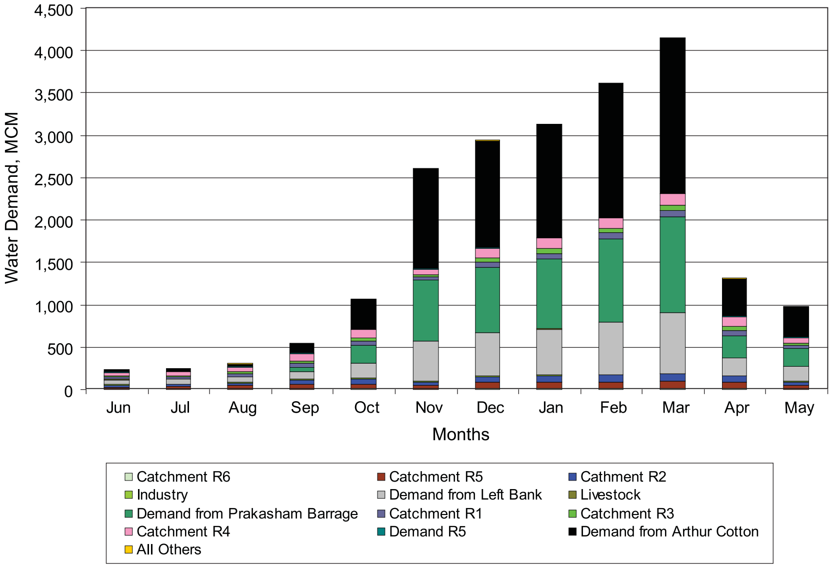
As 95 % of the cultivable area is already under irrigation (Bhaduri et al. 2007), it was assumed that substantial increases in new irrigated area will not be possible. Therefore, in the two scenarios, the agricultural land in the link command area was kept constant. Figure 2 shows WEAP set up with the link canal and reservoir. In both the Krishna and Godavari Deltas, agriculture is still the major water user compared to domestic and industrial demands (Figure 3) and increased agricultural production is the main goal of the Polavaram Project. Therefore, the anticipated benefits of building the Polavaram Reservoir and the link canal system are mainly based on the improved water supply and the subsequent increases in cropping intensity

Figure 2. WEAP set up with Polavaram link canal and reservoir.



Note: R1 till R6 represent the sub-watersheds in the Polavaram command area. The green arrows represent the water inflows from the supply sources and the red arrows are outflows from the demand nodes

Figure 3. Monthly water demands for 2003 from the catchments and other demand sites (excluding losses and reuse).



and yields. The effect of the Polavaram Project was tested by running the above two main scenarios under different crop rotation systems: i) paddy-paddy, ii) paddy- pulses (representing a low water intensity crop) and iii) sugarcane only. Each crop rotation condition was run with and without environmental flow (EF) requirements/demands. These cropping patterns reflect the regional practices of planting two paddy crops or only sugarcane if farmers perceive no water scarcity, and of planting paddy during monsoon and a low water intense crop (e.g., pulses, tobacco) during the dry season, under water-scarce conditions. The domestic, industrial and livestock water demands were kept constant in all runs. The scenario results were compared with each other and discussed in terms of unmet demands.

Defining Supplies and Demands

The starting point of the analysis was the development of catchment water demands. The demands in the study area are from agriculture, domestic sector, industry, and livestock. Each demand in the model is represented by a node. Monthly water demands from each demand node need to be assigned a priority level and linked to its available supply sources. Domestic water demand was given the first priority, followed by agriculture, industry and livestock – in that order.

In reality, each demand node also represents a certain geographical space. Therefore, in the model set up, the link canal command area was divided into sub-catchments based on a drainage map extracted from a digital elevation model (DEM). For the six sub-catchments (Figure 2 shows their boundaries) that fell under the link command area, demand nodes corresponding to agriculture and domestic demand were created. However, as livestock and industrial water demands were minimal, one demand node representing livestock and one demand node representing industrial demand were created for the entire command area. The demand data were available at mandal level (mandals are India’s third-level administrative subdivisions after state and district) whereas in the model, the sub-catchment represents the hydrological demand unit. Therefore, the mandals in the command area were assigned to the six sub-catchments by merging them together using geographic information systems (GIS). The demand nodes which were closer to the supply sources were given higher priorities.

The Agricultural water demand for each sub-catchment was calculated using the FAO Crop Requirements Method option in WEAP (FAO 1998). The domestic, livestock and industrial water demands were calculated using Indian government statistical reports (District at a Glance, 2003).

Water demands outside the link command area and that could be affected by the proposed water transfer were also added to the model set up. These additional demands include:

- Demands from mandals on the left bank command area of the Godavari River (Figure 1), based on the quantity of water to be transferred from the left bank canal (GOI 1999);
- Irrigation demands from the Prakasham Barrage;
- Irrigation demands from the Arthur Cotton Barrage.

The irrigation command areas of the Arthur Cotton and Prakasham barrages lie in the Krishna and Godawari deltas, downstream of the proposed Polavaram Reservoir and command area (Figures 1, 2). These additional demand sites were not represented in the model as catchments but as sites where a fixed quantity of water was extracted from the supply sources on a monthly basis. Each demand site was assigned a priority that determined the water allocation order. In Scenario 1, the Arthur Cotton Barrage command area in the Godavari Delta was given a higher priority than the irrigation demands in the link command area catchments. In Scenario 2, however, the link command area demands were given higher priority than the lower delta.

The supply sources built into the model were precipitation (for the catchments), surface water and groundwater. Precipitation was calculated based on the monthly data obtained from a climate station located in the Krishna Delta. Surface water flows in the Krishna and the Godavari were obtained from river gauging stations upstream of the Polavaram Project. Groundwater in the model was represented by a node and water availability was calculated based on the storage capacity and natural recharge values of the Andra Pradesh Groundwater Report (GoAP 1995; GoAP 2006). Simulations were conducted over the period from June 1991 to May 2005. The Polavaram Reservoir was simulated using the salient features published in the government feasibility report (GOI 1999). According to this report, the link canal is designed to transfer 5,325 MCM of water per annum. The proposed dam operating rules are not described at a monthly time step. Therefore, in the model, the reservoir releases were based on seasonal variations in water demand i.e., more water is transferred during the dry season.

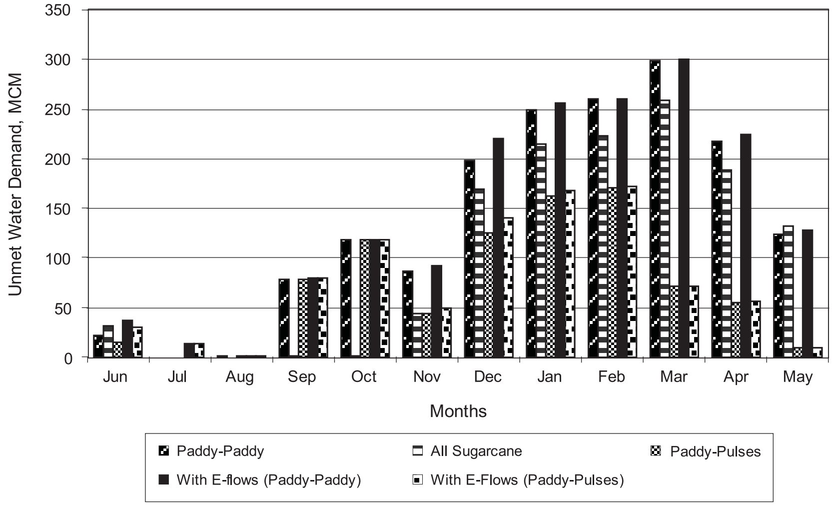
The EF requirements have been estimated using the desktop method described by Smakhtin and Anputhas (2006). The method takes into account the limitations of available hydrological and ecological information in India at present, but ensures that elements of natural flow variability are preserved in the estimated environmental flow time series, as required by the contemporary hydro-ecological theory. The method is based on the use of a flow duration curve – a cumulative distribution function of monthly flow time series. The curve is calculated for several categories of aquatic ecosystem protection – from ‘largely natural’ to ‘severely modified’, and the required EF volume and elements of flow variability are set to progressively reduce with the decreasing level of ecosystem protection. The EF calculated for the least acceptable category, Class D (‘largely modified’ rivers), was used in this analysis. In the model runs with EF requirements, the highest priority was given to environmental demands. The runs with EF requirements used a paddy-paddy and paddy-pulses rotation.

Results

Scenario 1: Reference Scenario with Current Water Use

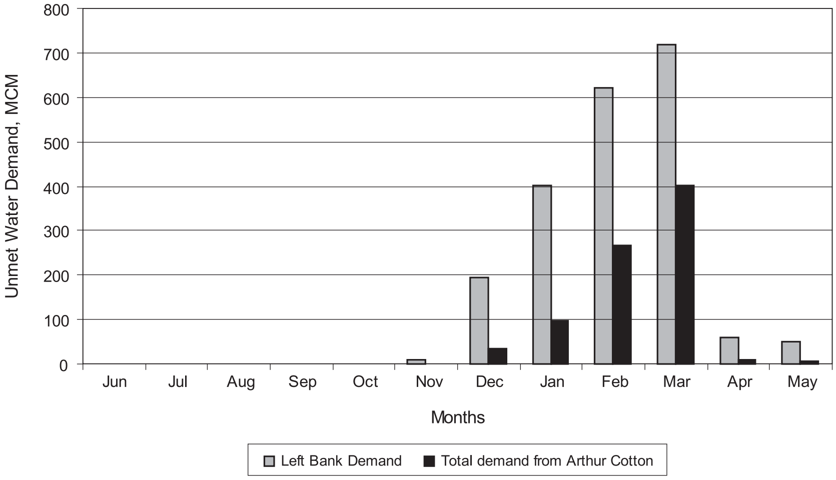
Under the current water use system, the average annual unmet demand for the period from June 1991 to May 2005 in the command area of the link canal is 1,655 MCM for a paddy-paddy system. Figure 4 shows the monthly average unmet demands aggregated for agriculture, domestic use, industry and livestock for the link command area. The unmet demands occur in all months except July and August (peak of the monsoon), and are for surface water as no further withdrawal from groundwater is possible. The maximum withdrawal rates from groundwater were based on the storage capacity and groundwater recharge rates for the area. Changing cropping patterns may decrease the unmet demands. For example, planting only one paddy crop during the rainy season and pulses (a low water intensity crop) during a rabi season will decrease water deficits up to 51 % (Figure 4). As expected, giving EF (even very small ones - corresponding to the least acceptable environmental Class D) a high priority in the water allocation scheme, increased the unmet demands for other users (agriculture, industry, domestic). The unmet demands are highest for the simulation, which combines paddy- paddy rotation and EF requirements (Figure 4).

Figure 4. Scenario 1: Monthly average (1991-2004) unmet demands from agriculture, domestic use, industry and livestock for the sub-watershed falling under the link command area, under different cropping patterns and with the inclusion of environmental flows. All cases include conjunctive surface and groundwater use.



Annual demands from the Arthur Cotton Barrage are 8,199 MCM for irrigation and 378 MCM for domestic and industrial use (GOI 1999). Assuming these demands are coupled with a paddy-paddy cropping system, the mean annual simulated unmet demand for the command area of the Arthur Cotton Barrage in the Godavari Delta would be 818 MCM. This constitutes 10 % of the mean total annual demand. The model also considered loss and reuse during transmission. For the areas outside of the Polavaram link command area, groundwater information was not available. Therefore, the demands in the model were linked to surface water supplies. Bhanduri et al. (2007) showed that groundwater is used in this area (Table 1). Consequently, the unmet demands at present are probably being met by groundwater extraction. The water deficit in the Godavari Delta is in the rabi and dry seasons (December to May – Figure 5). There is no deficit in the months from June to November. Therefore, the analysis shows that although there may be surplus water during the kharif season, in other months, there is a deficit in the Godavari Delta, which is being met by groundwater. In the area supplied by the Prakasham Barrage in the Krishna, the annual total demand is 5,139 MCM (GOI 1999). The model calculated 27 MCM of annual average unmet demand after 2003. Similarly, 2,057 MCM mean annual unmet demand were calculated for the left bank command area in the Godawari. Similar to the Arthur Cotton Barrage command area, water deficit in the left bank command area is only in the rabi and dry seasons (December to May, Figure 5).

Figure 5. Scenario 1: monthly average (1991-2004) unmet demands based on water requirements from Arthur Cotton Barrage and the Polavaram left bank command area.



In order to check if EF requirements are met in the Krishna under present conditions, the estimated EF for Class D were plotted against measured flow from the gauging station at Vijayawada (Figure 6). The Vijayawada gauge is downstream of the Prakasham Barrage. As can be seen from Figure 6, the situation in recent years has worsened as more water is being used upstream for various purposes. Annual analysis for the Godavari showed that within the 14-year modeling period, the EF requirements are not met during the dryer years (based on rainfall data). Figure 7 illustrates that the unmet EF requirements are highest in June, when water demand for agriculture is high. The unmet EF plot seen in Figure 7 is simulated with a paddy- paddy cropping pattern. Delays in the onset of the rainy season will affect water availability for EF. Paddy sowing was assumed to start in June, therefore, if the monsoon does not start in June, irrigation water demand will increase. The EF for class D is met from August to November.

Figure 6. Class D environmental flow requirements plotted against measured flow from the gauging station at Vijayawada.

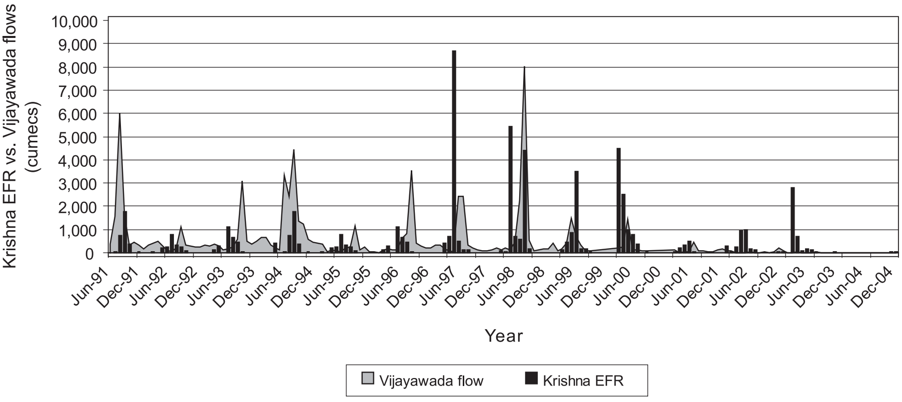
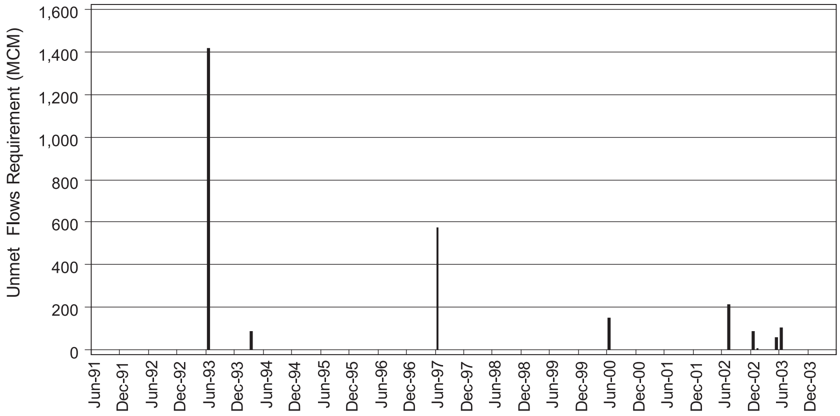


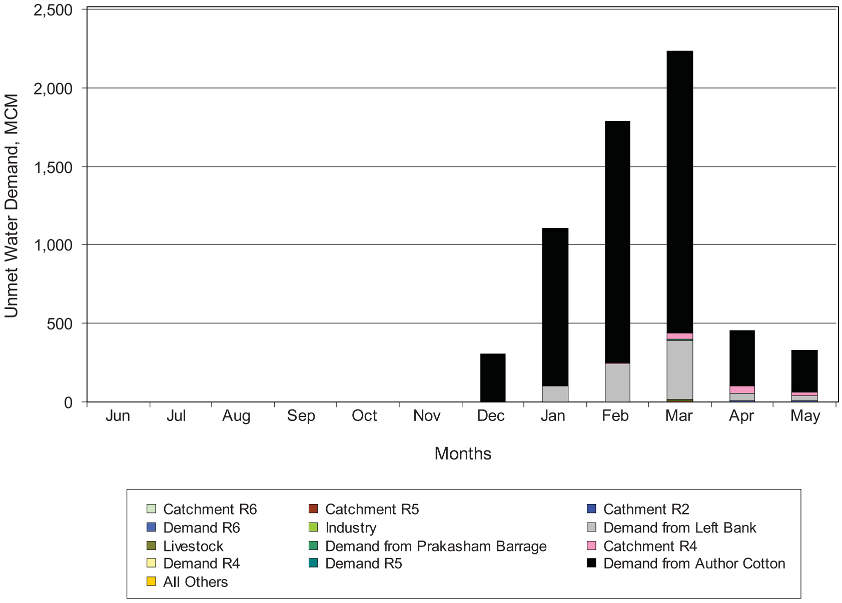
Figure 7. Scenario 1: Unmet environmental water demand under current conditions with paddy-paddy cropping pattern (environmental flow requirement is given the highest priority). The simulation was run with the paddy-paddy cropping pattern.



Scenario 2: With the Polavaram Reservoir and Link Canal

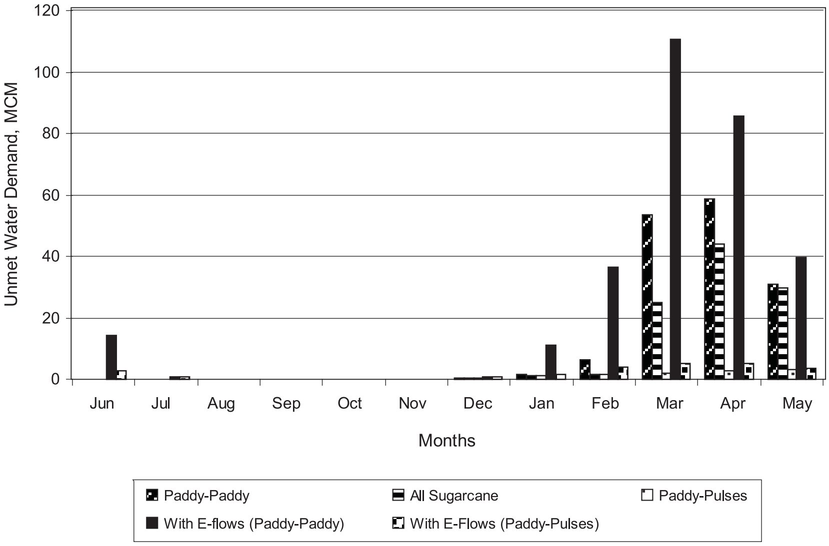
The simulations with the link canal and reservoir show that within the link command area, there are minimal unmet demands for agriculture, domestic, and livestock requirements (Figure 8). Figure 9 shows monthly average unmet demand (for 1991-2004) for agriculture, domestic use, industry and livestock for the link command area under different cropping

Figure 8. Scenario 2: Monthly average (1991- 2005) unmet water demands under paddy-paddy crop rotation. Unmet demands in the link command area are minimal compared to those in Arthur Cotton area and the left bank.



patterns as well as with EF requirements. The unmet demands occur during the period from December to June and changing the cropping pattern to paddy-pulses almost nullifies the unmet demands, which exist under other crop rotations (Figure 9). This is definitely an improvement for the link command area compared with Scenario 1 (Figure 4). Introducing EF for the downstream of the Krishna and the Godavari, especially coupled with a paddy-paddy cropping pattern, increases the unmet demands during the months of January till June (Figure 9). When comparing these values to Scenario 1 in Figure 4, one can conclude that although the water deficit situation improves within the link command area, if and when EF requirements are set, there will be a deficit in the link command area under a paddy- paddy cropping system.

Figure 9. Scenario 2: Monthly average (1991- 2004) unmet demand for agriculture, domestic use, industry and livestock for the link command area under different cropping patterns and with the inclusion of environmental flows. All cases include conjunctive surface and groundwater use.



The mean annual unmet demand for the left bank command area was 799 MCM and the Arthur Cotton command area was 5,270 MCM. Compared to Scenario 1, water deficit is smaller for the left bank command area, but higher for the Arthur Cotton Barrage command area, which is expected since water in the Godawari is being stored and diverted to the Polavaram command area. As with the current situation (Scenario 1), the water deficit in the Arthur Cotton command area is only in the rabi and summer seasons (December to May). The unmet demands situation for the Prakasham Barrage irrigation area shows improvement as there was no water deficit, with the exception of the year 2003, which was a particularly dry year. This water deficit occurs again only in March and can be alleviated by growing pulses or another lower water-intensive crop during the rabi season. Therefore, the analysis with the link canal (Scenario 2) showed that although the pressure on water resources within the left and right bank command area reduces, there will be increased deficit in the Arthur Cotton command area. This deficit is however, only during the rabi and summer seasons.

In this analysis (Scenarios 1 and 2), demands from the mandals in the link command area were also supplied with groundwater but, due to lack of groundwater recharge data from the Arthur Cotton Barrage, Prakasham Barrage and the left bank command area, demands were linked to surface water availability. In reality, however, a part of the unmet demand used in the analysis is met by groundwater. It is possible that increased aquifer recharge due to irrigation in the Polavaram link command area will provide additional groundwater resources for the lower delta where the Arthur Cotton Barrage command area is located. However, more studies are necessary to make accurate predictions on the sustainability of groundwater use. A key objective of the Polavaram Project is also to reduce groundwater use. Therefore, if groundwater pumping in the lower delta is increased (due to less water delivered), in order to maintain the existing levels of agricultural production, then this objective will not be met and the pressure on the natural aquifers will increase.

Figure 10 shows a graph of simulated storage volumes for the Polavaram Reservoir. The monthly net evaporation as published in the government feasibility report was used to calculate the evaporation losses from the reservoir. The reservoir reaches the inactive zone (3,381 MCM) during every dry season, which means that the water stored during each monsoon season will be utilized during the dry season of that same year. The reservoir storage capacity does not provide storage nor ensure water for inter-annual variations.

Analysis for the Godavari showed that within the 14-year modeling period, the EF requirements were not met during June in 1993, 1997, 2000 and 2003. In the simulation presented in Figure 11, EF requirements were set under a paddy-paddy cropping pattern where paddy sowing was set to start in June. Therefore, as the agriculture demands during this month are high, and if the monsoon rains that start usually in June are delayed, there will be unmet

Figure 10. Simulated storage volume of the Polavaram Reservoir.

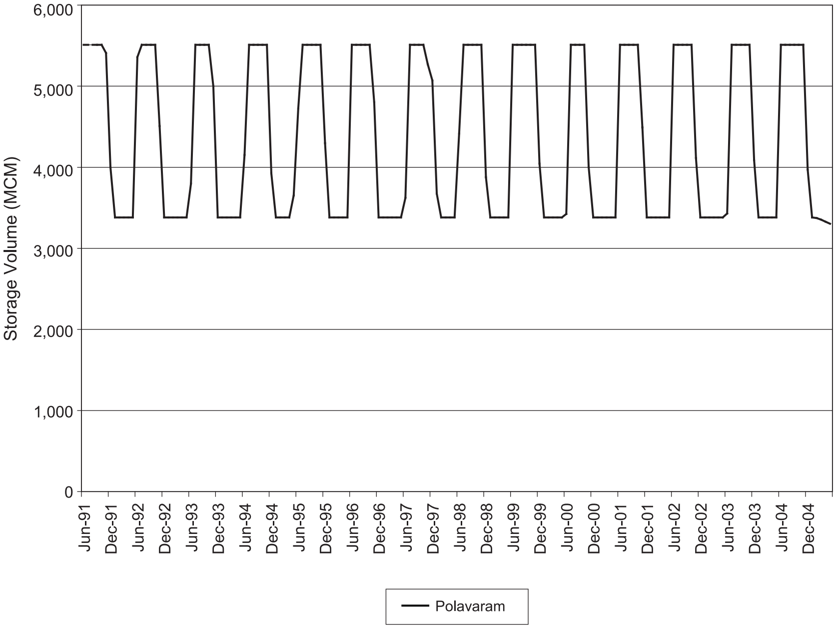
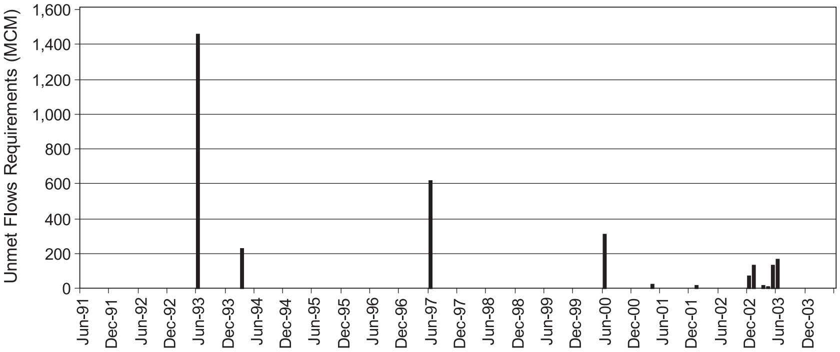


Figure 11. Scenario 2: Unmet environmental demand under a paddy-paddy cropping pattern and with environmental flows having the highest priority.



demands for agriculture as well as for environmental requirements. In both scenarios, June has the highest unmet EF for the Godavari. The storage in the Polavaram, as mentioned above, is utilized within each year, therefore, in this case, the reservoir also does not provide water to compensate for delays in the onset of the monsoon rains. The EF requirement situation, which is more critical in the Krishna (Figure 6), does not improve after the link and water transfer, as most of the water that is transferred will be utilized for en route irrigation demands. In the Krishna, the highest unmet EF demands are also in June and July - at the start of the monsoon season.

Conclusions

This study suggests that water resources management in the region has to be done on a seasonal basis by taking monthly variability into consideration. The simulations show that the proposed Polavaram Reservoir and link canal will reduce the seasonal pressure on water resources for the proposed command area of the reservoir. However, this will result in increased water deficits during rabi and summer months in the Lower Godavari Delta, which is being supplied through the Arthur Cotton Barrage. Therefore, water deficits may simply be transferred from one area to another. The water deficits exist only in the dry months. Changing cropping patterns, such as planting paddy during the monsoon and a low water intensive crop such as pulses in the dry season in the link command area, will decrease unmet demands for the Lower Godavari Delta. However, this will not be enough to continue the present water use patterns in the Arthur Cotton command area.

Similarly, the need to ensure EF should also be considered in the context of seasonal variability, as it is mostly in the dry months that the water allocation problems become critical. In the Godavari, it will not be possible to meet EF requirements in June, just before the start of the monsoon if the onset of the rainy season is delayed. Meeting EF requirements in the Krishna is a bigger problem than in the Godavari and the situation is not likely to improve even after the Polavaram Project, as most of the water that is being transferred will be used for en route irrigation.

In this study, the analysis for the transfer is done purely in hydrological terms as the main justification for the NRLP is based on the transfer of ‘surplus’ waters to ‘deficit’ basins. It is however, also recommended to integrate economic analysis into the assessment, whereby the benefits of the project’s incremental water supply can be compared against the losses (e.g., second season rice crop in the Godavari Delta). The planning of water transfer schemes should also consider the land and production loss, displacement costs and other impacts associated with water infrastructure development. Despite many attempts, it was not always possible for the authors to acquire the best input data available and, as such, a number of assumptions had to be made. Available economic and social analysis information looks similarly fragmented (GOI 1999).

Inter-basin water transfers have been an integral part of water resources management all over the world. However, without careful integrated planning and analysis, the proposed high-investment schemes might not be able to operate as planned and eventually might not deliver the expected long-term benefits.

Acknowledgments

The study is a part of the research project on the assessment of the National River Linking Plan (NRLP). The project is funded by the Challenge Program for Water and Food. Continuing data acquisition efforts by Dr A. Gaur and Jeanphilippe Venot (IWMI-India) are gratefully acknowledged. The authors are grateful to Dr H. Turral and Dr. Chandrashekhar Biradar (IWMI- Colombo) for valuable comments on this paper.

References

Amarasinghe, U.A.; Sharma, B.R.; Aloysius, N.; Scott, C.; Smakhtin, V.; de Fraiture, C. Sinha, A.K and A.K. Shukla 2005. *Spatial variation of water supply and demand across river basins of India.* Research Report 83. Colombo, Sri Lanka: International Water Management Institute.

Bhaduri, A.; Amarasinghe, U.A.; Shah, T. 2007. Assessing the Irrigation Benefits of India’s River Linking: Case Study-Godavari Krishna Link. Mimeo (draft). International Water Management Institute.

Biggs, T.W.; Thenkabail, P.S.; Gumma, M.K; Scott, C.A.; Parthasaradhi, G.R.; Turral, H. 2006. Irrigated Area Mapping in Heterogeneous Landscapes with MODIS Time Series, Ground-truth and Census Data, Krishna Basin, India. *International Journal of Remote Sensing* 4245-4266 (22).

Census of India, 2001. Government of India. New Delhi, India: Government of India Press,

FAO (Food and Agriculture Organization). 1998. *Crop evaporation guidelines for computing crop water requirements.* FAO Irrigation and Drainage Paper No. 56. Rome, Italy: Food and Agriculture Organization.

Government of Andhra Pradesh (GoAP) 1995. Modernisation of Krishna Delta System Project Report. Hyderabad, India: Irrigation and Command Area Development Department.

Government of Andhra Pradesh (GoAP). 2003. Statistical Hand Book for West Godavari District. Hyderabad, India: Directorate of Economics and Statistics.

Government of Andhra Pradesh (GoAP). 2003. Statistical Hand Book for East Godavari Hyderabad, India: Distict. Directorate of Economics and Statistics.

Government of Andhra Pradesh (GoAP). 2003. Statistical Hand Book for Vishakapatnam Hyderabad, India: District. Directorate of Economics and Statistics.

Government of Andhra Pradesh (GoAP). 2003. Statistical Hand Book for Krishna District. Hyderabad, India: Directorate of Economics and Statistics.

Government of Andhra Pradesh (GoAP). 2006. Groundwater Resource 2004-2005. A.P GWD Formats Vol. 1 and Vol. 2. Hyderabad, India: GoAP.

GOI (Government of India). 1999. Integrated water resources development. A plan for action. Report of the Commission for Integrated Water Resource Development Volume I. New Delhi, India: Ministry of Water Resources.

Government of India (GoI). 1999. The Feasibility Report of the Polavaram Vijayawada Link. New Delhi, India: National Water Development Agency. Ministry of Water Resources. (http://nwda.gov.in/index3.asp?sublink2id=33).

SEI-Stockholm Environment Institute. 2001. WEAP: Water Evaluation and Planning System – User Guide. Boston, USA: Stockholm Environment Institute,

Smakhtin, V.U.; Anputhas, M. 2006. *An assessment of environmental flow requirements of Indian river basins.* Research Report 107. Colombo, Sri Lanka: International Water Management Institute.

Smakhtin, V.U.; Gamage, N.; Bharati, L. 2006. Hydrological and Environmental Issues of Inter-basin Water Transfers in India: A Case of the Krishna River Basin. (in prep)

Yates, D.; Sieber, J.; Purkey, D.; Huber-Lee, A. 20005. WEAP21—A Demand Priority and Preference Driven Water Planning Model: Part 1, Model Characteristics. Water International 30 (2005). 487-500.

Yates, D.; Purkey, D.; Sieber, J.; Huber-Lee, A.; Galbraith, H.; West, J.; Herrod-Julius, S. 2007. A physically-based, water resource planning model of the Sacramento Basin, California USA. *ASCE Journal of Water Resources Planning and Management.* (in press).

Zerah, M.H. 2002. *Water supply and sanitation in Vijayawada: Analysis of household's situation towards modes and cost of access, consumption and level of satisfaction*. CESI – Report Number 2/2002. Centre for Economics Studies in India. pp. 43-46.

Hydrological and Environmental Issues of Inter-basin Water Transfers in India: A Case Study of the Krishna River Basin

V. Smakhtin, N. Gamage and L. Bharati
International Water Management Institute, Colombo, Sri Lanka

Introduction

The National River Linking Project (NRLP) was proposed as 'the solution' to water-related problems in India. It envisages transferring the waters of the Ganga, Brahmaputra and Meghna rivers through Mahanadi and Godavari river basins—all normally referred to as , 'water surplus' basins—to the 'water deficient' basins in the south and the west (e.g., http://www.riverlinks.nic.in/). The NRLP is a contentious issue in Indian society, the media and among academics. Many scholars argue that the needs assessment of the NRLP is inadequate. Others are of the view that the assessment of water surplus/deficits in Indian river basins, conducted as part of the NRLP proposal, has ignored environmental issues. And there are others who think that definitions of surplus and deficient basins need to be made more explicit and that alternative water management options—those that are less costly, easier to implement and more environmentally acceptable—have not been considered.

Extensive work has been done in India on various aspects of water transfers relating to the NRLP. However, the project as a whole has not reached implementation which, to a certain degree, mirrors the fate of certain other large-scale water transfer projects in the world. At the same time however, certain individual NRLP links are about to be constructed. Perhaps, one of the major reasons for the slow development of the project is the lack of clarity and transparency in technical design, justification of transfers and in decision-making on the one hand, and the enormity of both the challenge and the scale of the transfer, on the other. In an ideal world, any water transfer project may be justified if it satisfies the following broadly defined criteria (Inter-basin water transfer 1999):

1. The area of delivery to which the transfer of water is made must face a substantial deficit in meeting present or projected future water demands after consideration is given to alternative water supply sources and all reasonable measures for reducing water demand.

2. The future development of the area of origin, from which the transfer of water is made, must not be substantially constrained by water scarcity. However, such constraints may however be tolerable if the area of delivery compensates the area of origin for productivity losses accruing from the transfer.

3. A comprehensive environmental impact assessment must indicate to a reasonable degree of certainty that it will not substantially degrade the environmental quality within the area of origin or area of delivery. However, transfers may be justified where compensation to offset such environmental injury is provided.

4. A comprehensive assessment of socio-cultural impacts must indicate to a reasonable degree of certainty that it will not cause substantial socio-cultural disruption in the area of origin or area of water delivery. However, transfers may be justified where compensation to offset potential socio-cultural losses is provided.

5. The net benefits from transfer must be shared equitably between the area of transfer origin and the area of water delivery.

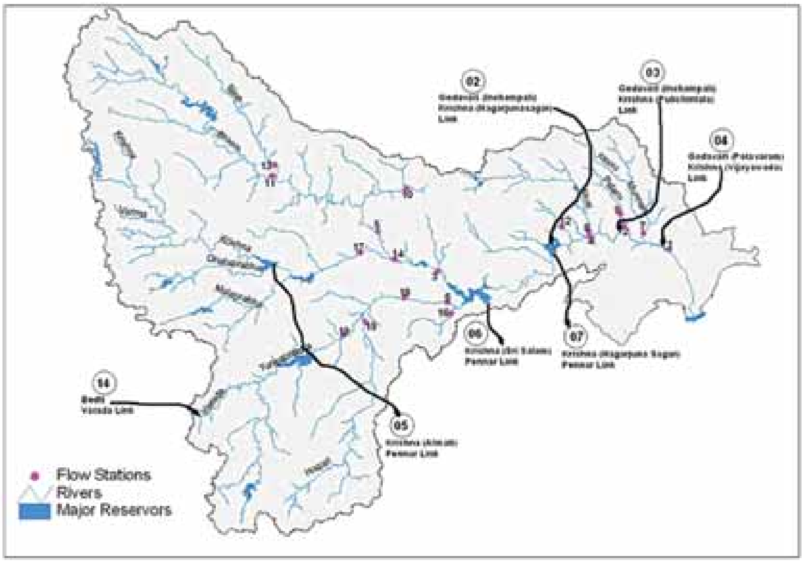
The International Water Management Institute (IWMI) is conducting a research project, which aims to highlight, discuss and, where possible, resolve certain controversial issues pertaining to the NRLP, thus further stimulating the debate on India's water future. This paper is one of the multiple outputs of this research project. The primary focus of the paper concerns the hydrological feasibility and environmental impacts of the NRLP, which are reflected by criteria 1, 2 and 3. The objective of the paper is not to analyze all of the NRLP's links from all possible angles of technical and environmental feasibility, but rather the authors aim to: i) identify and examine those technical and environmental aspects which may still have been under-appreciated in previous discussions on the NRLP and need to receive further attention; and ii) illustrate their importance on one or several (but very few) of the NRLP's links. More specifically, this paper first briefly describes the proposed links in and out of the Krishna River from / to adjacent river basins (Figure 1). Krishna is a major river basin, spanning three states in peninsular India.[1] This is followed by the discussion, using certain links as examples, on how water transfer planning may be affected by the resolution of the hydrological data. The paper further focuses on the environmental aspects of one of these links: Godavari (Polavaram)—Krishna (Vijayawada)—Figure 2. This link is the most downstream one in the Godavari-Krishna system and one which is currently being constructed. A contemporaneous paper by Bharati et al. (2007) discusses the multiple aspects of water management of Polavaram—Vijayawada link and examines the impacts of water management options and scenarios using an integrated Water Resources Evaluation and Planning model (WEAP).

---

[1] The Krishna Basin is one of five 'benchmark basins' in which IWMI conducts research from around the world, where the intention is to integrate various strands of bio-physical, socioeconomic and institutional research.

Figure 1. A schematic map of India, showing the boundaries of the major river basins/drainage regions of the country. 1, 2 and 3 are Godavari, Krishna and Pennar basins, respectively.

Figure 2. A schematic diagram of the Krishna River basin, showing all proposed inter-basin water transfers in and out of the basin (black lines with numbers) together with flow measuring points (stations) for which some observed flow data were available for the study. Link numbers are circled and correspond to the overall NRLP numbering system. Station numbering is for identification purposes only. Due to the low quality, short records or inappropriate location relative to the link points, only a few of the shown stations are usable. These include record at station 3 (Krishna at Agraharam) and part of the record at station 1 (Krishna at Vijayavada).



Water Transfers In and Out of the Krishna Basin: A Review

In order to assess the degree to which the criteria 1, 2 and 3 above are satisfied in the planning of individual links in and out of Krishna, the relevant chapters of the technical feasibility reports (Hydrology, Environment), produced by the National Water Development Authority (NDWA) of India, have been reviewed. Most of the reports are available on the NWDA site in HTML format (http://nwda.gov.in/indexab.asp? langid=1). A brief summary of each link with the authors' comments is given below on Figure 2, starting from the most 'upstream' link.

Bedti–Varada Link (Link 14)

This is the only incoming link in the upstream part of the Krishna Basin for which no feasibility report is available at present. The salient features of the link are listed on the NDWA web site, together with very limited anecdotal information (Dams, Rivers and People 2004). This proposal envisages the diversion of 242 million cubic meters (MCM) of 'surplus' waters from the Bedti Basin (in Western Ghats - flowing west into the Arabian Sea; not shown in Figure 2) to the water 'deficient' Tungabhadra subbasin in Krishna (Figure 2). The water will be used to irrigate approximately 60,200 ha of land and for hydropower generation. Two new dams in the Bedti Basin will be constructed with a combined total (live) storage of 98 (85.5) MCM. The larger reservoir will be connected by a link canal to a tributary of the Varada River.

So far, no environmental studies have been conducted around this link. The small tributaries involved in this project, however, may be very sensitive to flow changes. Also, located in the humid tropical forests (75 % of the area) and declared by the International Union for Conservation of Nature (IUCN) as a biodiversity hot spot, the basins to be affected host 1,741 species of flowering plants and 420 species of birds and other wildlife. This exceeds the biodiversity numbers from the whole of Kerala State, which is where the Bedti Basin is located. The flow will be discharged into the Varada without a receiving reservoir, which may increase channel erosion in the localized parts of the river. Altered flow patterns may also cause riparian zone degradation and create habitats for invasive species. The proposed project is expected to generate 3.6 MW of power, but it may take over 61 MW to lift the water to the Varada.

Krishna (Almatti)–Pennar Link (Link 05)

This is one of the several links effecting water transfers from the Krishna Basin to the Pennar Basin (Figures 1 and 2). The link starts from the existing Almatti Reservoir on the Krishna River (upstream catchment area 33,375 km2). This link is seen as a partial exchange for Godavari water brought into Krishna (links 2, 3 and 4 on Figure 2). However, since all the inward links from Godavari bring water to the downstream parts of Krishna, and since the inflow from Bedti link (if constructed) is minor, this link effectively transfers the existing 'surplus' water from the upstream reaches of an otherwise 'deficient' Krishna Basin into another 'deficient' basin in Pennar. The purpose of the link is to satisfy en-route irrigation needs. The 1980 MCM of water will be transferred through a 587 km long canal with an outfall into a tributary of Pennar. A new (balancing) reservoir with a total (live) storage of 83 (73) MCM is to be constructed at the recipient end in the Pennar Basin - at Kalvapalli village with an upstream catchment area of 5,616 km2. The need for this new reservoir may need to be better justified as there is another dam (upper Pennar) which commands the catchment area of 5,245 km^2 - just upstream of the proposed new one.

All water transfers in the NRLP are planned from ‘surplus’ basins or parts thereof to ‘deficit’ basins. The basin is declared ‘surplus’ if both the balance of water ‘naturally’ available (assured) in a river is 75 % and 50 % of the time positive and the total demand for the next 25-50 years upstream of the point of a transfer is also positive. If this balance is negative, the basin is perceived as a ‘deficit’ one. (The details of the methods used to establish whether a basin is surplus or deficit are described and discussed later in this paper). At Alamatti, the ‘surplus’ water at 75 % and 50 % assurance (‘dependability’ – in Indian terminology) is estimated to be 5,611 and 8,247 MCM, respectively, while the corresponding figures for the recipient point of Pennar at Somasila are deficits of -3,820 and -3,590 MCM, respectively. Such a large difference between surpluses and deficits of the donor and receiving basins is the major justification for the transfer.

The major feature of this link is the long canal, and a lot of attention is paid to the justification of its design and cost. It will pass through reserved forests and a bear sanctuary, where 17 wildlife species are reported including four endangered ones. Losses of and disturbances to the habitat due to the lined canal becoming an obstacle to wildlife migration routes, are programmed into the project. However, it is suggested that such affected wildlife ‘will migrate to surrounding forests’ instead, and thus the canal’s impact on wildlife will be minimal. Possible measures to mitigate the disturbance to the sanctuary include re-aligning it and establishing a ‘minimum protected area’. The Kalvapalli reservoir is anticipated to provide a waterfront for wildlife. The equivalent of about US$35,000 (in 2006 dollar terms) is allocated in the project for the improvement of the environment.

Water pollution in the Kalvapalli is anticipated in the form of silting and sedimentation, nutrient leaching and agricultural runoff containing fertilizers and pesticides. As such, common mitigation measures – such as contour bunding - are planned. A beneficial aspect of the project is an anticipated increase in fish production. The link canal is seen as a facilitator of cross-migration in fish species, which will increase the overall fish population, although no justification for this or evidence from other similar cases is provided. Most ecological issues considered in this feasibility report are related to the link canal rather than to the donor or the recipient rivers per se. It is possible to suggest that no ‘ecological’ releases from the Almatti Dam are made or planned because there is no mention of such releases.

Krishna (Srisailam)–Pennar Link (Link 06)

This is one of the several links effecting water transfers from the Krishna Basin to the Pennar Basin. The link starts from the existing Srisailam Reservoir on the Krishna River (with an upstream catchment area of 211,657 km^2) at the latter’s confluence with the Tungabhadra River (Figure 2). Similarly to the Almatti – Pennar link upstream, this link effectively transfers the existing ‘surplus’ water from the otherwise ‘water deficient’ Krishna Basin into another ‘water deficient’ basin in Pennar. This may result in less water downstream of the Srisailam Dam and cause the reach between Srisailam and Nagarjuna Sagar dams to become even more water deficient. The 75 % and 50 % assured annual flows at Srisailam are estimated to be 57,398 and 66,428 MCM, respectively, although the final surplus at 75 % assurance is, after all demands are satisfied, at 6,017 MCM. 2,310 MCM of water will be diverted through the existing Srisailam right main canal, which will operate 6 months a year from July to December (monsoon and post-monsoon season). The water will be discharged into the Nippulavagu, a natural stream, and will reach Pennar through the Galeru and Kunderu tributaries. No new infrastructure is required and no en-route irrigation is planned, and the transfer targets exclusively as its destination, the Pennar and Cauvery basins. (It has to be noted, however, that older transfers of this nature have resulted in the development of irrigation along the canal and capture of that water). As with other links, no provisions exist for environmental releases downstream of the Srisailam Dam. Certain common impacts of water diversions (e.g., sedimentation of reservoirs, changes in the hydrological regime due to flow regulation, waterlogging and salinity caused by irrigation and drainage) are discussed in general terms.

The major point made with regard to this link is that since there is no new storage and water is to be transferred through partially concrete-lined natural streams, there are no new submergence areas, waterlogging, or adverse impacts on flora and fauna. It is suggested that the conveyance streams can easily carry an additional 163 m3/s of water (the amount of water transfer for 6 months in a year) in addition to their own ‘natural’ discharges. It remains unclear how these streams will react to extra water during the 6 months, and what the riparian conditions are or how embankments will affect fish spawning.

Krishna (Nagarjunasagar)–Pennar Link (Link 07)

This is a major transfer of 12,146 MCM of water from and to existing reservoirs: the Nagarjunasagar Dam on the Krishna (upstream area of 220,705 km^2) and the Somasila Dam on the Pennar. The 75 % and 50 % assured ‘natural’annual flows are 58,423 and 67,346 MCM, respectively. The purpose is to improve irrigation en route (where irrigation facilities are not adequate) and then to transfer water further to the south, where water shortages are said to be more severe (a deficit of -3,820 MCM is envisaged at 75 % assurance in Pennar with all irrigation plans in place). A new 393 km long lined link canal and an existing right-bank canal from Nagarjunasagar will run in parallel over 202 km, while the latter can only carry 3,979 m3/s annually the proposed link-canal is expected to transfer three times more water. Such massive transfers may only be possible due to the chain of transfers from further north. The restructuring of the existing right-bank canal is not possible and, therefore, the construction of a new one is seen as a necessary option. Because no new storage is associated with this link, the feasibility report envisages no environmental impacts and nor costs are for mitigation of those. This link is effectively part of the much longer water transfer line from the north to the south. Additional water transfer to Nagarjunasagar reservoir is planned through Inchampalli- Nagarjunasagar link (see below).

Godavari (Inchampalli)–Krishna (Nagarjunasagar) Link (Link 02)

This link involves the transfer of 16,426 MCM of water and a construction of a new major storage reservoir on Godavari at Inchampali. The upstream catchment area at this point is 269,000 km^2 and the gross (live) storage of the future dam is 10,374 (4285) MCM. A low ratio of a live storage to gross is noteworthy. The water yields of the Godavari at Inchampali at 75 % and 50 % assurance are estimated to be 66,193 and 76,185 MCM, respectively. The proposed irrigation plans are huge and in all states involved, they exceed the sum of existing and ongoing irrigation projects. These plans are effectively the justification of the transfer. The irrigation requirement projected for the year 2025 on the basis of states' irrigation plans is 40,723 MCM and the balance of all demands (irrigation plus others) at 75 % and 50 % assurances is 20,327 and 29,987 MCM, respectively. The Krishna River at Nagarjunasagar is estimated to have a deficit of -1,525 MCM at 75 % assurance, which is another justification for the transfer. This water transfer is justified by a large irrigation development, which in itself will probably take many years to complete, and the feasibility of which would depend on the cost of water provided.

From the environmental side, the major impacts are perceived to be related to the submergence area of the new reservoir, which leads to major resettlements. It is suggested, however, that aquatic life will develop in the new reservoir and that, for example, the loss of breeding grounds of crocodiles in the river due to submergence is negligible. The paper indicates that the project will have an impact on the Singaram Sanctuary and submerge 65 ha of the Indravati National Park. It lists the known present fauna and birds in the area, which however does not include any endangered species. Although no adverse impacts on aquatic life are identified, the paper was not able to cite any studies which have been carried out in this regard. Afforestation is proposed to compensate the loss of forests to submergence.

Godavari (Inchampali)–Krishna (Pulichintala) Link (Link 03)

This link will divert 4,370 MCM of water from the Godavari into a new reservoir on the Krishna at Pulichintala, with a gross storage capacity of 1,296 MCM, through a new, 312 km - long link canal. The water yields at 75 % and 50 % assurances are estimated to be 66,193 and 76,185 MCM respectively and the surplus surface water balances after satisfaction of all projected requirements at Inchampali are at +20,327 and +29,987 MCM, respectively. Similar estimates are done for the Muneru, Paleru and Musi tributaries of the Krishna.

The feasibility report explicitly suggests that all requirements in the Godavari, downstream of Inchampali, can be met by the water available from the incremental catchment area located between the Inchampali and Dawlaishwaram barrages and with the surplus water transferred from the Mahanadi. Therefore, no water is likely to be released from the Inchampali downstream and all water at Inchamapali will instead be diverted to the Krishna. The feasibility report refers to simulations of the Inchampali reservoir at a monthly step, over the period of 1951-1981, supplying both the Pulichintala and Nagarjunasagar links (4,370 and 16,426 MCM respectively). Simulations suggest that all requirements will be satisfied with a success rate of 76 %. The environmental issues associated with this link are the same as those with the Inchampali - Nagarjunasagar link, as they are for a common storage (Inchampali).

Godavari (Polavaram)–Krishna (Vijayawada) Link (Link 04)

This is the most downstream link in both the Godavari and Krishna basins, and the one which is scheduled for construction in the near future. It is planned to divert 1,236 MCM of water from the new Polavaram reservoir in the Godavari (with a live storage of 2,130 MCM) to the existing Prakasam barrage in the Krishna, through a new 174-km long link canal. The transfer is designed to substitute releases to the Krishna delta from the Nagarjunasagar Dam and to allow 'saved' water to be used for other projects in the Krishna. The canal, operating throughout the year, will discharge into the Budameru – a river which flows into the Koleru

Lake (now effectively a large collection of aquaculture ponds) - and from there the transfer will go through the Budameru diversion canal, discharging into the Krishna 8 km upstream of the Prakasam barrage. There is already considerable infrastructure in the lower Godavari, below the proposed Polavaram reservoir. Lift irrigation stations along the river provide irrigation in the lower Godavari delta. This may decrease the total area expected to benefit from the Polavaram link. There is also no mention of how the existing canals will be integrated into the new canal system if and when it's operational.

Approximately US$600,000 (0.2 % of the project cost) is allocated: i) to study the 'environmental and ecological' aspects of the project by various organizations; and ii) for protective measures as may be necessary. Since both donor and receiving points are nearly at the outlets of the Godavari and Krishna rivers, environmental impacts may only be felt in both deltas and en-route of the canals, where new irrigation, and domestic and industrial requirements are targeted. Possible adverse impacts mentioned in the paper include resettlement, submergence of forest, waterlogging and salinity in the command area. Planned mitigation measures include drainage systems in the command area to mitigate salinity, fish ladders through the Polavaram to allow for movement of migratory fish, studies of the nature of existing aquatic weeds in the submerged area as well as other areas.

The National Council of Applied Economic Research (NCAER) of Delhi, India, was entrusted with the studies of socioeconomic and environmental implications of six inter-basin water transfers including this link (Agricultural Finance Corporation 2005). Their report indicates that the wildlife sanctuary in the proposed Polavaram reservoir area will be marginally affected by the submergence. In addition, the report indicates a list of fauna in the area coming under submergence, compiled on a district by district basis. It is also suggested that wildlife conditions will actually improve due to the broad expanse of water in the new reservoir, which is conducive to breeding wildlife. The report however is unclear as to the scientific basis for these conclusions. It is further envisaged in the report that endangered species such as the tiger and the panther will move to deeper forest areas and avoid the submerging areas.

It is indicated that the construction of the Davlaishwaram anicut in the Godavari has obstructed fish migration from the sea to the inland (e.g., hilsa). It is stated that the dams convert a river into a more placid lotic environment with reduced velocities, which impacts the composition and size of fish species. However, the report fails to present any quantitative, link-specific conclusions in this regard. Generic statements are also made about phytoplankton, and changes in seasonal flow pattern etc. It is also admitted that the entire command area lies in the coastal belt where there is high rainfall, which enhances the risk of malaria. In addition, a few general statements are made about vector breeding and a possible increase in waterborne diseases.

The Environmental Management Plan section describes a variety of relevant measures including catchment area treatment through vegetative measures and structures (to reduce the inflow of extra sediments into the reservoir), development of flora and fauna through compensatory afforestation, enhancing of aquaculture through the stocking of the new reservoir with exotic fish species, relocating certain archeological structures, and disaster management (concluding that there is no possibility of a breach in the dam because probable maximum flood waters will be diverted by the structure). The report, however, does not address delta-relevant environmental issues such as reduced flow of water and increased sediment deposit into the deltas due to dam construction, resulting in stunted delta growth, seaside erosion or mangroves' degradation etc.

General Observations

Overall, all NWDA feasibility reports are succinct summaries of the proposed inter-basin water transfers. They have similar structures and level of detail and represent, effectively, the only source of publicly available technical information on the proposed transfers. As such, these reports are very valuable.

At the same time however, they all share similar shortcomings. The information presented remains limited and it is not possible to judge the quality of the data used. Environmental aspects and impacts of the proposed projects are only generally described and, are primarily related to the submergence area associated with the new reservoirs and the resettlement of the population affected. It is clear that no provision is made for the in-stream ecological releases from either existing or planned reservoirs. If a proposed link is to flood or otherwise affect existing wildlife sanctuaries, the latter are expected to be relocated / compensated, implying their relatively low importance. The general comments on environmental impacts make no reference to the link/site in question and cite no supporting studies. In addition, the technical aspects of certain links need more clarity. For example, the Bedti-Varada link does not seem to be justified from the hydropower angle (as it will produce far less energy than the amount used to transfer the water). Links starting from lower Godavari include the construction of a new Inchampali reservoir, which is designed to have a very low ratio of live to gross storage, making it a huge evaporation tank. The entire complex of inter- basin water transfers is driven by significant irrigation expansion that extends into the year 2050. At the same time, it is not entirely clear where this new land for irrigation expansion is located, because most of the proposed ‘new’ irrigated land in the Krishna and Godavari basins is likely to be irrigated already (H. Turral, IWMI, pers. comm.). The approach can however, benefit more from more integrated, basin-wide water resources planning. At present, water is planned to be transferred from the upper parts of the Krishna Basin, while at the same time other links will deliver water into the Krishna downstream. The reported low benefit / cost (B/C) ratio of certain projects is also noteworthy. For example, the Almatti - Pennar and Polawaram - Vijayavada links both have the B/C ratio of around 1.2, which makes the effectiveness of these links questionable. Finally, the methods by which water availability for the transfers were calculated require comment and are discussed in the next section.

How Much Water is Actually Available for Transfers?

A Summary of the ‘Official’ Water Resources Planning Method

The methodology that the NWDA is using in planning water transfers is essentially the same for all links and is described in abbreviated form in every individual feasibility report. It is important to attempt to spell out this method here because the NRLP has been criticized for not describing the basis on which the assessment of water availability and identification of surplus and deficient river basins have been made. This is a misconception, because the issue is not so much that the assessment is unclear, but rather whether it is entirely appropriate given the scale of transfers. The overall planning approach includes several sequential steps:

- The catchment upstream of the diversion point (Donor) or receiving point (Receiver) is separated into several smaller subbasins to cater for the spatial variability of rainfall and runoff over large areas. The number of subbasins varies with the links – depending on the size of the catchment area upstream of the link point. For smaller links, like the Bedti -Varada, such separation is not required and one subbasin may be used. Observed annual flows at one or more hydrological measuring stations (e.g., in every subbasin) are calculated using original flow records. The observed records used different time lengths for different links. For example, a period of 100 years (1900-2000) is used for the Almatti link, while a period of 32 years (1951-1983) is used for the Srisailam link.

- Since the observed flows are normally affected by various water abstractions, all these abstractions are calculated and 'added back' to the observed flows. It is not entirely clear from the feasibility reports how this is done since the types of abstractions differ, they have increased over time, especially in the last 20 years, and there is no inventory of the various abstractions in India. (The latter is partially due to the competitive nature of interstate water management, where each state tends to leave its abstraction data undisclosed to its neighbors). Regardless of the methods used, accounting for these abstractions attempts to 'naturalize' observed river flows, because these flows form the reference condition for assessing water availability for the transfer.

- The annual time series of weighted areal rainfall for each gauged basin is then calculated using the data from available / selected rainfall stations, and a regressive relationship between annual naturalized flows and annual areal rainfall is established.

- This regression analysis is then carried out for the entire subbasin (which is ungauged) using the monsoon rainfall time series as input. This allows the monsoon period flows to be calculated for each year. The non-monsoon portions of flow are then added to the monsoon portion for each year thus building the annual time series of naturalized flows. It is not clear from the feasibility reports how the non-monsoon portions are calculated, but the perception is obviously that these flows do not provide a significant contribution to the overall volume of annual total flow.

- The calculated annual flow time series for individual subbasins upstream of the Donor/ Receiver site is then summed up to produce the annual time series for the naturalized flows at the link point. This time series is then presented in the form of a cumulative distribution (a type of a flow duration curve analysis), which shows the probability of exceedence of every annual flow in a record. This probability is termed 'dependability' in Indian practice (an alternative term 'assurance' is often used in other countries). This exercise allows flows occurring at the site to be visualized and interpreted all at once. The lower the flow is at the donor site, the more 'dependable' it is because flows in other years frequently exceed it. The higher the flow however, the less dependable it is. Floods are difficult to capture because they occur less frequently.

- The cumulative distribution function of annual flows at the Donor/ Receiver site is used to estimate flows (‘gross yields’ in Indian terminology) with ‘dependabilities’ of 50 % and 75 %. The selection of these assurances of supply although rather arbitrary is not the most critical issue, since many different levels of assurance of water supply larger than 50 % are conventionally (and similarly arbitrarily) used worldwide in the practice of water resources engineering (e.g., Smakhtin 2001).
- The annual flows at 50 % and 75 % assurances (further demoted as Q50 and Q75) are the major components of the water supply estimates. Other components include regeneration and known imports from other river basins. Regeneration (most likely an equivalent of ‘return flows’), is estimated as 10 % of the net utilization from all present and future irrigation schemes and as 80 % of the domestic and industrial uses to be met from surface water sources. The total water supply (WS) is calculated by summing up the assured flows with regeneration and imports and deducting exports, if any:

$$WS_{p\%} = Q_{p\%} + Imports + Regeneration - Exports \qquad (1)$$

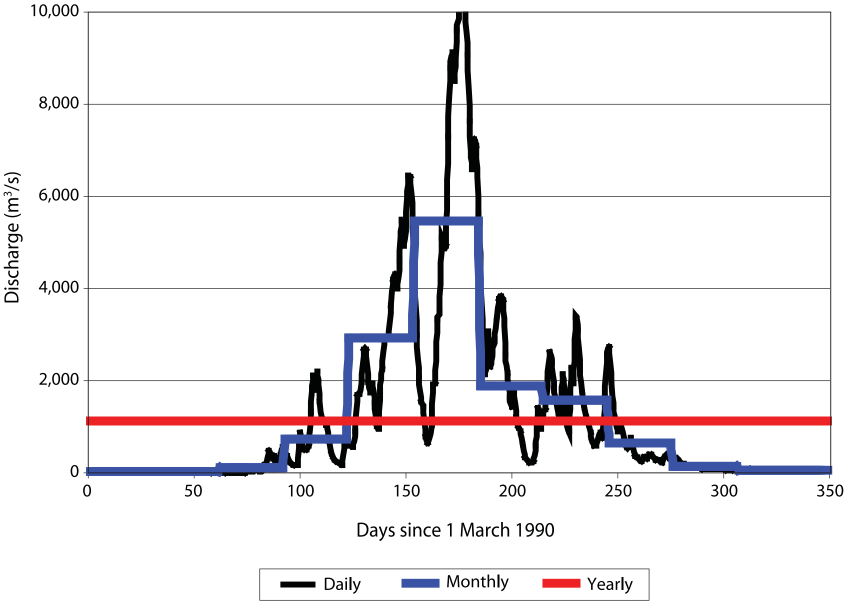
  where: p % denotes the assurance (50 % or 75 %). All calculations so far are prepared at the *annual* time step. Most of the further decisions are based on the estimates derived from annual flows at 75 % assurance.
- Various demands are then estimated and projected for either the year 2025 or the year 2050, depending on the link. Agricultural water demands are estimated based on state plans for irrigation development. The industrial requirement (assumed to be met entirely from surface water sources) is not known and is taken to be equal to the domestic water demand, which is based on population figures. The hydropower requirement is taken to be equal to the total evaporation from all hydropower projects. Environmental water demands are not however, accounted for in the estimates. When ‘downstream’ requirements are mentioned, they normally imply the requirements of downstream agriculture, industry or domestic needs, but not aquatic ecology or recreation.
- The difference between the total available supply (equation 1) at 75 % assurance and the total projected demand at the same site (Donor or Receiver) becomes the basis of declaring the basin (or part thereof) as a ‘surplus’ or ‘deficit’. If the above difference is positive- the basin is a ‘surplus’, if negative – it is a ‘deficit’.
- As a rule, each link includes at least one reservoir – either at the Donor or at the Receiver point or at both points. The last step in the methodology is, therefore, a reservoir simulation modeled on the current day observed flows and including all future demands. This step is performed with a *monthly time step*. Annual flow data for the available period are used as the basis for calculations. All gross annual current upstream water requirements are subtracted from the gross annual flow time series. This gives a time series of annual actual inflows to a reservoir whether existing or

new (e.g., to Alamtti, Inchampalli, etc.). These net annual inflows are distributed into *monthly* values using weights obtained from the actual monthly flow data at one of the nearby flow stations. The records used to calculate the weights may be short (e.g., 10 years in the case of the Srisailam). It appears from the feasibility reports that average monthly weights are used for this calculation—i.e., monthly flow distribution is assumed to be the same in dry and wet years. Monthly irrigation requirements are then calculated based on crop needs. Initial storage (initial condition for reservoir simulation) is often assumed to be the dead storage (which is typical for India, where it seems to be a common practice to assume full draw down of the stored water every year and no provision for inter-annual storage). A reservoir simulation is carried out to identify whether the proposed transfer can be managed with the estimated storage and, if yes, then with what level of reliability—how many of the simulated years will be deemed successful years. A successful year is normally defined as a year in which 95 % of all demands are met (which is quite a conservative [good] measure of success).

The Issue of Data Resolution and Its Impact on Planning Estimates

It is clear from the above summary that flow data with annual time step resolution were used as the basis for the estimates of dependable (assured) flows at link points. This approach requires comment. The existing literature on water resources systems suggest that although annual time step data may be used for the preliminary (crude) planning of water supply systems, the preferred data type for this is the monthly flow time series (e.g., McMahon and Adeloye 2005). The issue of data resolution is not a superfluous one: data resolution significantly affects the information content of the hydrological time series. Figure 3 illustrates this point with the three most widely

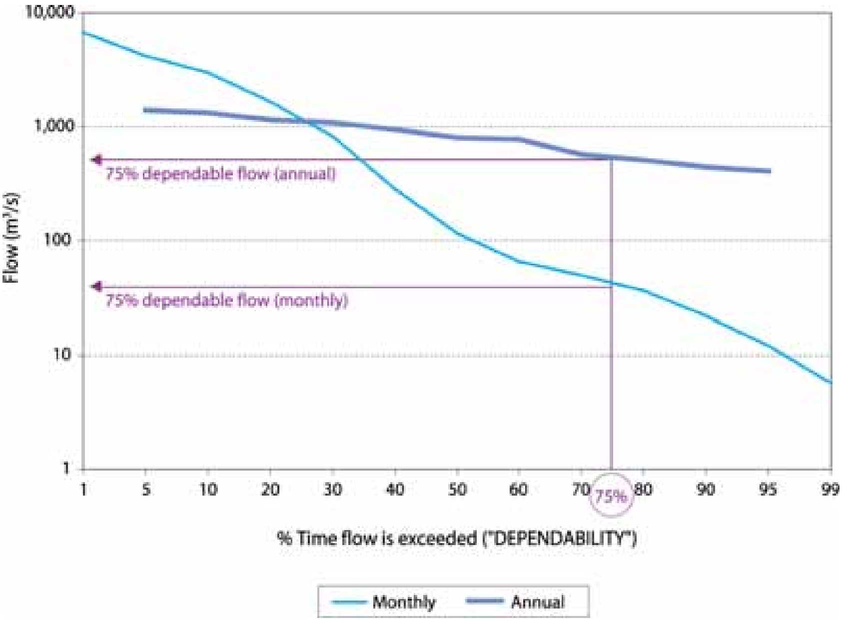
Figrure 3. An illustration of different temporal data resolution: yearly, monthly and daily flows recorded in the Krishna River at Agraharam Town during March 1990–February 1991.



used flow data types- annual, monthly and daily. The differences between daily and monthly flows in low-flow months are negligible due to minor variability of daily flows during these months. However, the differences between the mean flow for the 'year' and the mean monthly flows in different months are pronounced: 8 months out of 12 have flows significantly lower than the yearly mean. Annual data resolution, therefore, does not capture 'enough variability' in flows and can lead to the overestimation of available water throughout the year.

Figure 4 further illustrates the impact of data resolution on the calculation of 'highly dependable' flows. The figure shows flow duration curves (FDCs) constructed using the annual and monthly flow time series for the same arbitrarily selected site on the Krishna River, for which certain observed flow data were available. The flow exceeded in 75 % of all years (75 % dependable flow- in Indian terminology) and is much higher than the flow that exceeded 75 % of all months. NDWA feasibility reports use *annual* flow values at 75 % dependability as a measure of surface water availability at the points of transfer (both Donor and Receptor sites). However, if monthly, more information 'rich' data are used instead of annual flow values, the flow available at 75 % dependability amounts to a smaller magnitude than when annual data resolution is used.

Figure 4. Flow duration curves for the Krishna River at Agraharam Town based on 15 years of monthly flow data and constructed with annual and monthly aggregation levels.



The implications of the assessment of the water available for transfer at the links' points are clearly very significant, if such assessment is made by simply reading off the 50 % and/or 75 % assured flows from 'annual' or 'monthly' FDCs. The limitation of data available for this study prevented the carrying out of reliable calculations for all link points. Only very few data sets, primarily from the Internet, were available. The accuracy of these data sets is not possible to ascertain, but it is possible still to illustrate the abovementioned differences for certain links.

The link points for which dependable flows have been calculated are listed in Table 1. These are effectively the only link points which can be simulated with the limited data available.

To construct a FDC at Inchampali, the duration curve at Polavaram (both in the Godavari Basin) has been multiplied by the factor of 0.874 – the ratio of catchment areas at Inchampali (269,000 km2) and Polavaram (307,880 km2). The data period used was 1910-1960 (despite the availability of more recent observations) – to avoid the impact of missing data on both ends of the record, particularly after 1960 and in order to ensure that a less impacted, more natural flow time series was used. This record gives a long-term mean annual flow estimate at Polavaram of approximately 105 BCM, which is close to the 'official natural' flow estimate of 110 BCM (cited also in Smakhtin and Anputhas 2006).

To obtain a FDC at Vijayavada, which is representative of more natural and less regulated conditions, the curve at Vijayavada (Station 1 in Figure 2), established from the observed record of 1900-1965 (which retains more unregulated flows), has been scaled up by the ratio of mean annual flow for the above period and the 'official' estimate of the mean annual flow at the Krishna outlet, which is 78 BCM (cited also in Smakhtin and Anputhas 2006).

To obtain a FDC at Srisailam, the 'naturalized' duration curve at Vijayavada (Station 1 in Figure 2) has been multiplied by the factor of 0.84 – the ratio of catchment areas at Srisailam (221,657 km2) and Vijayavada (251,360 km2). The data period used was 1900-1965 (despite the availability of more recent observations) to avoid the impacts of the significant reduction of the Krishna flow observed in the last 50 years and to ensure a more or less 'unregulated' record.

To obtain a FDC at Almatti, the duration curve at Agraharam (Station 3 in Figure 2 – the nearest to Almatti with usable data) has been multiplied by a factor of 0.25 – the ratio of catchment areas at Almatti (33,375 km2) and Agraharam (132,920 km2). The data period used was 1983-2000 – the only period for which data at Agraharam were available. Since neither systematic data on water abstractions upstream of Agraharam nor 'natural' flow estimates at Agraharam from alternative sources were available, no corrections to the original flow data at Agraharam were possible. This may have lead to the underestimation of means and dependable flows. Observed data at Agraharam are historical data and are affected by upstream developments. The mean flow volume calculated at Agraharam from these data is 19,270 MCM, which is tiny compared to the assurances of 50 % or 75 % of flows in Table 1 taken from NWDA. It is clear that such a mean flow is not accurate and the error is transferred to the estimates of dependable flows at Almatti.

Also, flows do not always have a linear relationship with the basin area. However, the above simplifications are unlikely to lead to major inaccuracies compared to for example, differences in estimates from annual and monthly time step data. It has to be noted that should more reliable data become available, then the estimates in this study can be revised to ensure more compatibility with the data used in the feasibility reports.

Table 1 is presented for illustrative purposes – to show the remarkable differences between the two estimates in every case. It is noteworthy that, for example, the official estimate of the 'natural' flow at the outlet (Polavaram) is around 110 BCM (a corresponding estimate obtained from the data as described above is 105 BCM, which is rather close). However, the 75 % dependable flow at Polavaram is estimated to be 80.17 BCM (80,170 MCM in Table 1), which is around 73 % of the total long-term mean flow. While this estimate makes sense in the context of the annual time step used, it is virtually impossible to assume, that such an enormous amount of water may be a reasonable estimate of the water available 75 % of the time, given the high

Table 1. Estimates of surface water availability (MCM) at 50 % and 75 % dependability from annual (NWDA) and monthly (IWMI) data resolution for selected link points in and out of Krishna.

Donor /Receptor point	Dependability 50 %		Dependability 75 %	
	Annual data	Monthly annualized	Annual data	Monthly annualized
Krishna – Alamatti	24,041	958	21,405	326
Krishna- Srisailam	66,428	8,626	57,398	1,684
Godavari- Inchampalli	76,185	10,546	66,193	4,497
Godavari – Polavaram	96,549	12,155	80,170	5,132
Krishna Vijayavada	Not available	11,808	Not available	1,964

Source: Annual data are from the feasibility reports in http://nwda.gov.in/indexab.asp? langid=1. Monthly data are authors' estimates.

variability of flow within a year in the Godavari, and also that a year contains a large number of low-flow months (the case similar to that shown in Figure 3)

The Use of Spell Analysis for the Re-assessment of Surface Water Availability

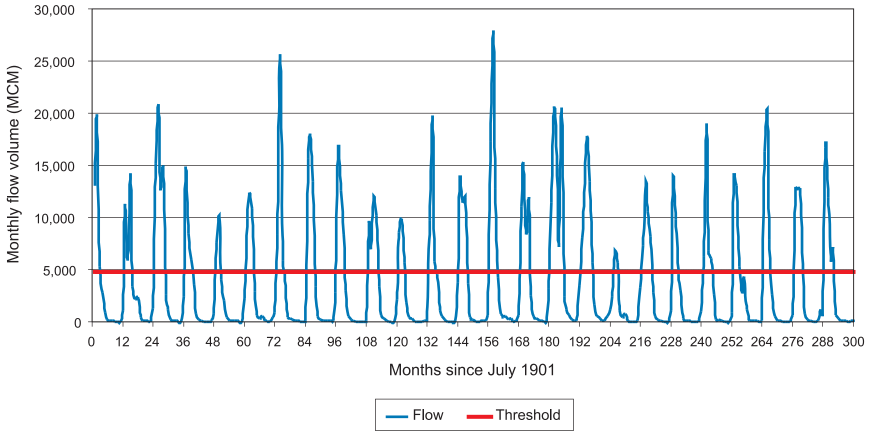
The two different data resolutions (annual and monthly) used to assess water availability effectively represent two different ways of thinking about the level of possible flow regulation. Annual flow data ignores within-year flow variability and, therefore, indirectly suggests that the river may be almost completely regulated for water supply. The use of monthly data (to assess water availability) implies that almost no future increase in abstraction is possible. Both approaches represent the extreme cases in water availability i.e. the 'annual' one unjustifiably pushes up water availability estimates while the 'monthly' one significantly reduces them. Neither of these approaches and their results is entirely acceptable. They may rather be thought of as representing the top and the bottom limits of assured water availability at a site.

It is perhaps more appropriate to use a form of water resources storage-yield analysis to establish the maximum possible draft (reservoir yield) at the donor point of each transfer. This analysis can be used to establish either the possible reservoir yield if a given/ planned storage is constructed, or the reservoir storage necessary for the required yield. In the context of estimating water availability (including water availability for transfers), a reservoir (or a system of reservoirs) could to an extent provide feasible maximum storage that will be used to make the water actually 'available'. The assessment of surface water availability then becomes equivalent to the assessment of the yield (draft) of the reservoir with the above maximum feasible storage. The approach still needs to be based on monthly data however, to capture the seasonal flow variability.

Storage-yield analysis is a discipline of civil engineering and its description is beyond the scope of this study, but it can be found in text books (e.g., McMahon and Adeloye, 2005). In this study, we use the approach of spells (runs), which may be seen as a component of storage –yield analysis. A spell (run) is a hydrological event when a river flow *continuously* stays below or above a certain threshold flow level. Each spell is characterized by the duration and excess or deficit of flow volume. For example, deficit flow volume is characteristic of a low-flow spell. Depending on the type of flow regime and the flow threshold, there may be one or several low-flow spell(s) in one year. Two transfer sites from Table 1—Krishna (Srisailam) and Godavari-Polavaram—are used below as examples to illustrate this alternative method of assessment of water availability. Other points were not or could not be considered either due to the lack of certain data, or the unreliability of available data or closeness to other gauging points.

In the case of the transfer at the Srisailam site, the NWDA estimated an available annual yield of 57,398 MCM - or a constant flow volume of 4,783 MCM per month throughout the year. Placed in the context of the spell analysis, this figure becomes the flow threshold, which needs to be satisfied. Analysis of the monthly flow data at Srisailam (generated as explained earlier) suggests that every year, there is a significant continuous flow deficit below this threshold (Figure 5). The deficits range from the minimum of 27,500 MCM to the maximum of 40,100 MCM. The latter, maximum deficit, may serve as a crude indication of the storage required to maintain the NWDA estimate of the water yield at the Srisailam site.

Figure 5. An extract from the monthly flow time series at the Srisailam site on the Krishna.



Given that the above estimate is rather crude, it is unlikely that without significant storage increase, water at the above high threshold can be made available. Also, while this storage is not impossible to construct in principle, as it is only approximately 60 % of the long-term mean annual flow at the site and there are dams with larger percentages than that, it is hardly practical because:

- The cumulative dam storage upstream of Srisailam at present is already 17.1 BCM. More storage will not only be detrimental to the upstream basin but also become inefficient in an already heavily regulated system
- The dead storage of such a dam (or a combination of dams) in a flat basin like the Krishna is likely to take up a large proportion of the total storage.
- No major additional storage construction is actually planned

A cumulative storage of 20 BCM (which is slightly higher than the already existing storage upstream of Srisailam) has been used here as an arbitrary but feasible value, in order to estimate how much water can realistically be made available. To achieve this, several runs with different flow thresholds have been carried out until the maximum deficit in the Srisailam time series has dropped to 20 BCM. The corresponding threshold flow is 2,700 MCM per month or 32,400 MCM on the annual scale.

A similar exercise has been carried out using the monthly flow time series at Polavaram. The total cumulative storage in the entire Godavari Basin (existing and planned as part of the NRLP) of 18.8 BCM has been elevated to 20 BCM to allow for limited additional but feasible storage growth in the future. The corresponding threshold flow in the Godavari at Polavaram has been estimated as 3,000 MCM per month or 36,000 MCM on the annual scale.

Tables 2 and 3 below include the above two alternative estimates of surface water availability, which are still significantly lower than the corresponding NWDA estimates (obtained using annual time step data). These estimates have been used with the data on various water demands presented by the NWDA, in order to determine the impacts of reduced surface water availability on the overall basin water balance. The various demands have not been revised and are taken in all cases as they are found in the relevant NWDA reports. The environmental flow requirements have, however, been estimated and added to the tables (these estimates have been prepared using the method developed by Smakhtin and Anputhas [2006] for the least acceptable environmental management category called class D with minimum possible environmental water demand). It has to be noted that this management class is, effectively, the 'last resort'- the one in which there is a large loss of natural habitat, biota and basic ecosystem functioning. This is a situation that responsible governments would be expected to avoid.

Table 2. Surface water balance (MCM) at the Srisailam Dam site, Krishna (211,657 km^2).

	NWDA		IWMI
Surface Water Availability		57,398	32,400
Surface water import (+)		-	
Surface water export (-)		7,848	7,848
Regeneration (+)			
Domestic use	2,624		
Industrial use	3,748		
Irrigation use	2,773		
Sub-total	9,145	9,145	9,145
Overall availability		58,695	33,697
Surface water requirement for (-)			
Irrigation use	43,559		43,559
Domestic use	3,278		3,278
Industrial use	4,687		4,687
Hydropower	1,154		1,154
Environmental use	N/a		5,300
Sub-total	52,678	(-) 52,678	(-) 57,978
Surface water balance		(+) 6,017	(-) 24,281

Source: Annual data are from the feasibility reports in http://nwda.gov.in/indexab.asp? langid=1. Monthly data are authors' estimates.

Table 3. Surface water balance (MCM) at the Polavaram Dam site, Godavari (307,880km^2).

	NWDA		IWMI
Surface water availability		80,170	36,000
Surface water import(+)		3,888	3,888
Surface water export (-)		13,318	13,318
Regeneration from (+)			
Domestic use	1,512		
Industrial use	2,402		
Irrigation use	3,138		
Sub-total	7,052	7,052	7,052
Overall availability		77,792	33,622
Surface water requirement for (-)			
Irrigation use	47,541		47,541
Domestic use	1,890		1,890
Industrial use	3,002		3,002
Hydropower (evaporation losses)	6,380		6,380
Consumptive use from Polavaram	3,808		3,808
Environmental use	N/a		8,200
Sub-total	62,621	(-) 62,621	(-) 70,821
Surface water balance		(+) 15,171	(-) 37199

Source: Annual data are from the feasibility reports in http://nwda.gov.in/indexab.asp? langid=1. Monthly data are authors' estimates

As the tables above illustrate, after significant reductions in surface water availability, which is the starting point in planning for inter-basin water transfers, the overall water balance of each basin has changed dramatically from being essentially 'water surplus' to seriously 'water deficit'. It is important to note that this change would occur regardless of whether environmental flow requirements are included as a component of water demand or not. In the first place, it is acknowledged that the estimates suggested here may not be very accurate due to severe data limitations. However, the change itself cannot be attributed to data inaccuracies or limitations, but clearly to the approach used for the assessment of surface water availability. It is envisaged that if the original data used by NWDA were available, it would still result in a similar change in water balance. The points made here attempt to attract attention to the need for increased accuracy in the overall planning process and to the need to revise the estimates of water availability and water balance using more advanced planning tools, a more transparent process as well as by accepting environmental water requirements as a legitimate demand similar to other water demands.

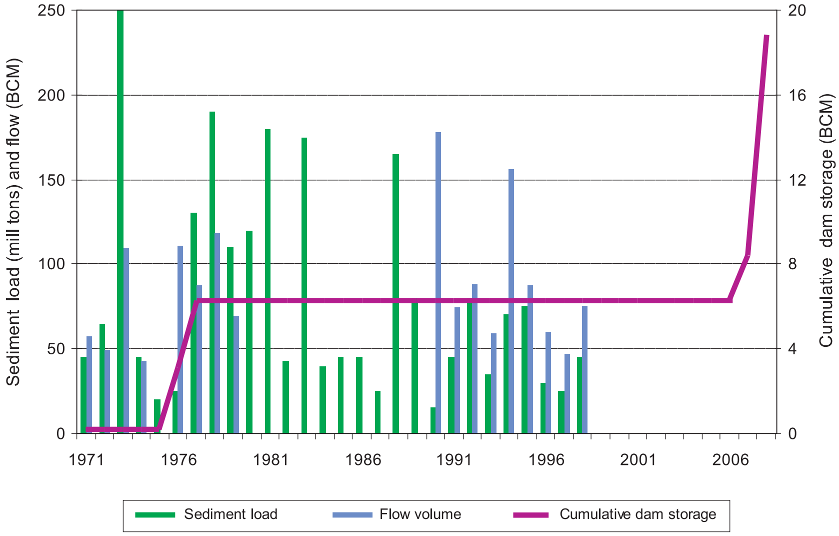
Environmental Impacts of Reservoir Construction on the Godavari and Krishna Deltas

Inter-basin water transfers are associated with the construction of new storage reservoirs. A lot has been said and written about submergence, resettlement (upstream) and the impacts of changing flow pattern on fish (downstream) – all of which are matters associated with reservoirs. At the same time, all in-stream storages irrespective of where they are in the basin or not, have impacts on river outlets. Given the number of reservoirs already constructed in both basins (Krishna and Godavari), as well as the planned massive storage construction associated with the NRLP, it is only natural to highlight the issues of upstream development impacts on deltas and estuaries. However, these issues have not been considered in the NWDA reports as there is a general tendency in water resources planning worldwide to ignore these issues. At the same time, depending on the river and the magnitude of upstream construction, such impacts may become significant.

Coastal Erosion: Godavari Delta

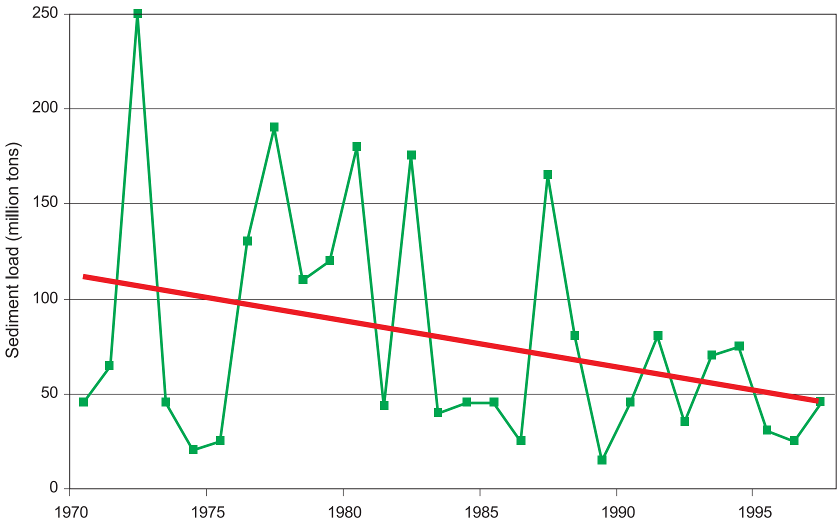
Malini and Rao (2004) examined the recent changes in the Godavari River delta, called the ‘rice bowl of AP’, using remote sensing images. They discovered that the delta has regressed landward with the total net land loss of 1,836 ha over the period of 1976-2000 (at rate of 73.4 ha/year). It was suggested that the reduced inflow of sediments, associated with upstream reservoir construction are the main causes of reduced vertical accretion at the delta. At the same time, coastal subsidence, probably promoted by neotectonic activity and consequent relative sea level rise, continued and led to a shoreline retreat. Figure 6 illustrates the dynamics of flow and sediment load at the outlet of the Godavari (at Polavaram) and the reservoir storage growth in the entire Godavari Basin since 1970. The flow time series has been taken from Internet sources, and the sediment load data have been read off similar sediment graph published by Malini and Rao (2004), while the storage data are derived from the ICOLD dam register. The flow time series does not include data during the period 1980-1990, and neither flow nor sediment data were available after 1998. Cumulative dam storage (including large and medium dams) increased significantly in the early 1970s and remained relatively constant for the last 30 years. However, it will increase abruptly again after the construction of the Polavaram barrage and the major Inchampali Dam (the growth of the total storage in the basin after the dam construction is shown in Figure 6 —an arbitrarily assumed completion date for the Inchampali Dam is the year 2010).

Figure 6. Time series of annual flows, sediment loads and cumulative storage in the Godavari Basin outlet at Polavaram.



While trends in the Godavari River flow cannot be ascertained from the available disrupted flow time series, the decreasing trend in annual sediment loads are manifest in the sediment data (Figure 7, also shown by Malini and Rao 2004). The mean annual sediment load has decreased from 100 million tonnes in 1978 (effectively an ending point in noticeable reservoir growth in the basin) to 46 million tonnes by the end of the 1990s. The current cumulative reservoir storage in the Godavari Basin remains relatively low (6.3 BCM, i.e., approximately 6 % of the mean annual flow at the outlet). The storage growth of the reservoir is not the only significant indicator of the volume of water transferred, as much of the water is also diverted from barrages, which are structures without storage. The fact that the sediment load remains at a noticeably decreasing trend in relatively small basin storage implies that the basin sediment regime is very sensitive to reservoir growth, if the reservoir growth remains to be seen as the main source of the problem. More sediment inflow reduction may, therefore, be expected after the construction of the Polavaram and Inchampalli storages, which will increase the basin storage to the natural flow ratio in the basin to 19 %.

Figure 7. Time series of sediment load at Polavaram with a decreasing trend line.



Coastal Erosion: Krishna Delta

In this study, an attempt has been made to examine whether similar trends exist in the Krishna Basin, where the proportion of storage viz., annual flow is much larger than in the Godavari. The observations on sediment loads at the Krishna outlet at Vijayavada over the last 30-40 years have, however, not been provided by the Central Water Commission (CWC) during the course of the study. The only available data were for the period of 1991–2000 (CWC 2006), which is a rather limited time series for any meaningful conclusions on trends to be made. The comparison of the two short time series of sediment loads at Agraharam (upstream of major reservoirs, Figure 2) and at Vijayavada (downstream of all major dams) has revealed a significant decrease in sediments downstream of the reservoir system (Figure 8). The differences are particularly noticeable in the high-flow years (1994, 1999), when more sediment reaches Agraharam from the relatively unregulated upstream basin. However, all sediments are likely to be trapped by the existing reservoir system

(Srisailam, Nagarjunasagar) upstream of Vijayavada. The absence of sediment data prior to 1991 does not allow further conclusions to be made about sediment regime changes, even though, these changes are most likely to be very significant due to the marked reduction of river flow at the Krishna outlet (Figure 9) over the last 70 years. This reduction is due to various water diversions, groundwater development and increased cumulative reservoir storage in the basin, which has grown from almost zero in 1960 to 28.5 BCM at present. This present cumulative storage represents 36 % and 132 % of the natural and present day Krishna mean annual flow, respectively.

Figure 8. The time series of sediment loads in the Krishna at Agraharam and Vijayawada.

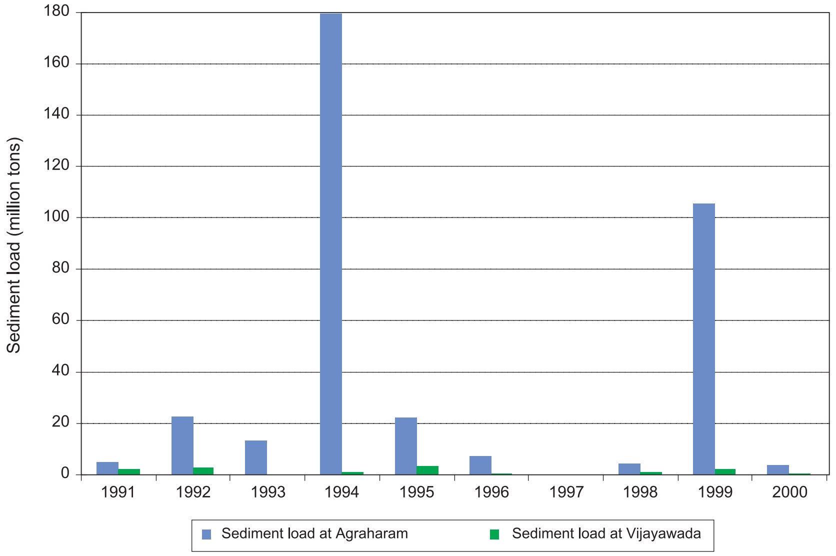
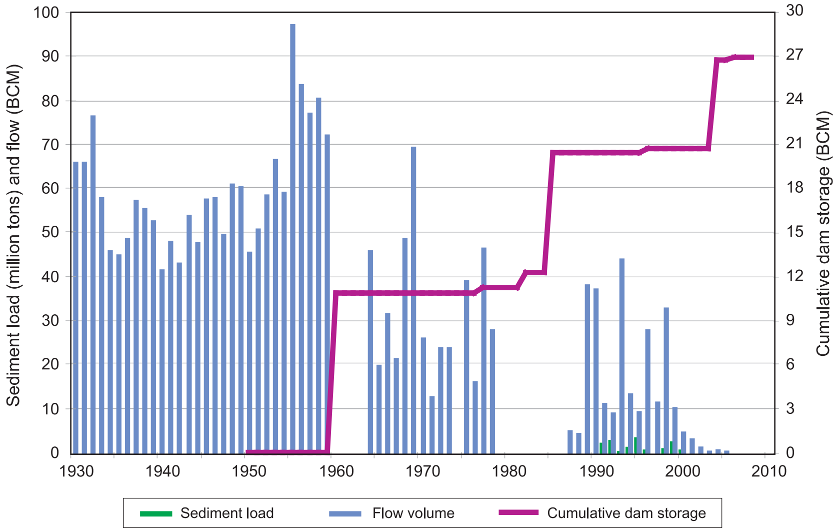


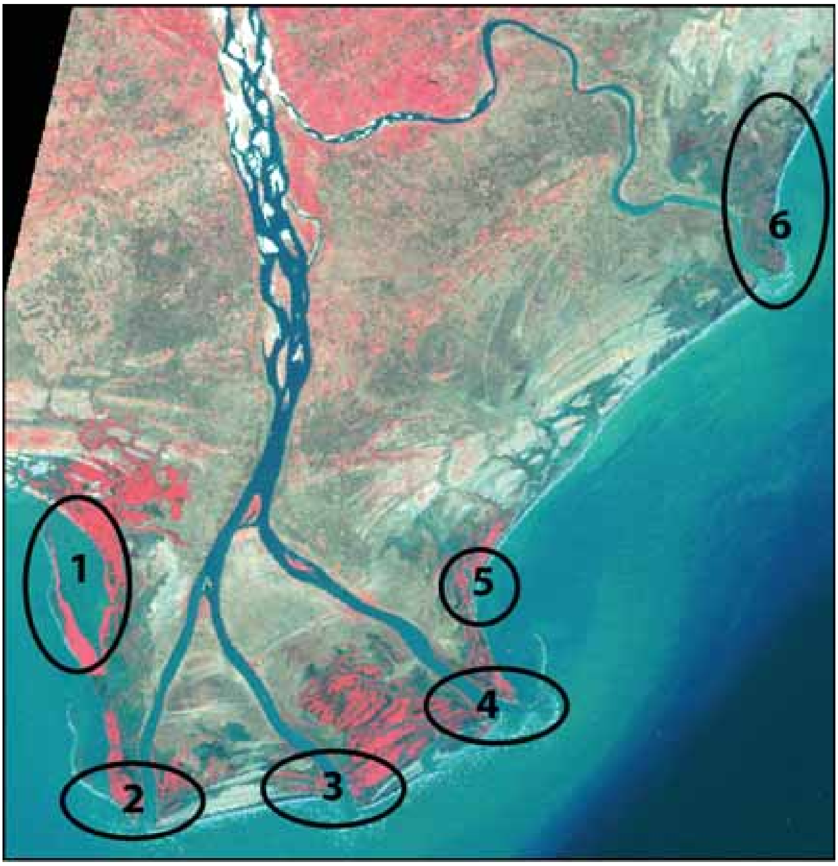
Figure 9. Time series of annual flows, sediment loads and cumulative storage in the Krishna Basin outlet at Vijayawada.



To examine the potential impacts of reduced sediment inflow on the Krishna delta, several remote sensing images of the area were analyzed. The images were obtained from the Earth Science Data Interface (ESDI) at the Global Land Cover Facility (GLFC), found at http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp and were selected from the period between 1977 and 2000 to form a ‘time series’. The images included:

- Landsat 2 Multispectral Scanner (MSS) image dated June 1, 1977 with a spatial resolution of 57 m;
- Landsat 5 Thematic Mapper (TM) image dated November 10, 1990 with a spatial resolution of 28.5m; and
- Landsat 7 Enhanced Thematic Mapper (ETM+) image dated October 28, 2000 with a spatial resolution of 28.5m .

Figure 10. The image of the Krishna River Delta indicating the areas where a closer inspection of erosion and deposition was made.



Three basic layers were used to detect morphological changes in the delta: (a) band 4 (NIR); (b) band 2 (Red); and (c) band 1 (Blue). These layers have characteristics that are suitable for coastal mapping, differentiation of vegetation from soil, reflectivity of deneness of vegetation and delineation of water bodies. The first, 'oldest' image was assumed to be the reference condition against which changes in other two images were detected. The entire delta shoreline was examined to demarcate the zones of erosion and deposition using ERDAS 9.0 software. The areas of deposition and erosion in between two consecutive dates (i. e., at 1990 and 2000) were identified and calculated using ArcGIS software. The areas around selected points (primarily the mouths of the main distributaries), where significant changes were expected to occur, were closely examined, highlighting the zones of erosion and deposition at each point. The image of the Krishna delta showing selected areas where the detailed assessment of erosion and deposition has been made is presented in Figure 10. Figures 11 and 12 display the sequence of images for years 1977, 1990 and 2000 for certain selected areas circled in Figure 10. The black lines in each image represent the reference position of the land mass at the start of the period – in 1977. Figure 13 shows areas of predominant erosion and deposition during the period between 1977 and 2000 for the entire delta shoreline, while Table 4 summarizes the calculated characteristics of these processes for the entire delta over the same period.

Figure 11. The changing morphology of the selected area 2 in 1977, 1990 and 2000. The top and bottom rows of images show the dynamics of the right and left banks of the distributary, respectively.

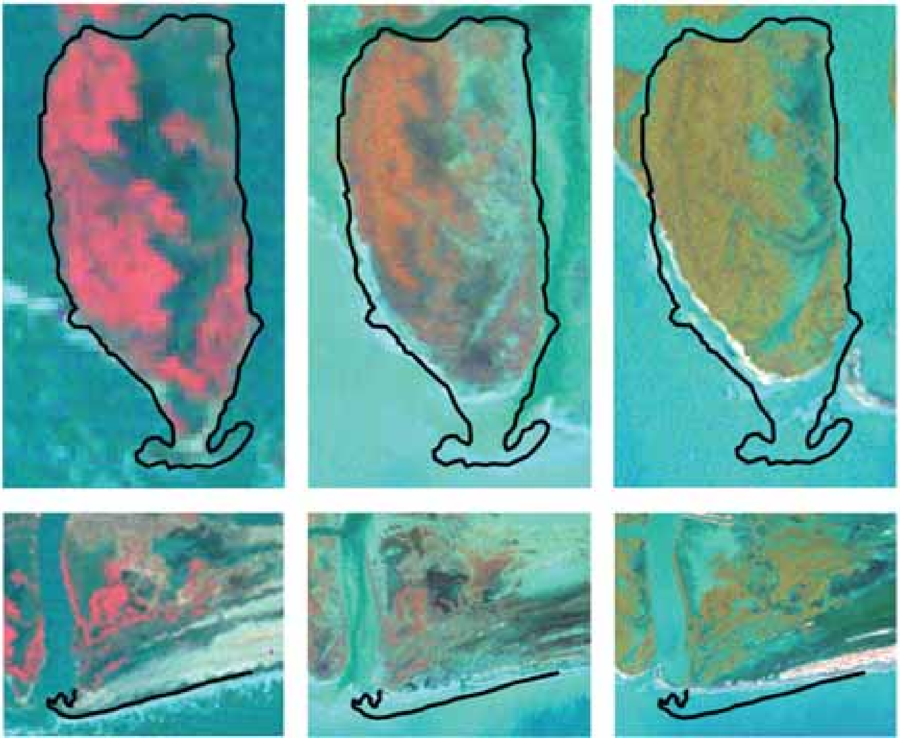


Figure 12. The changing morphology of the selected area 4 in 1977, 1990 and 2000. The top and bottom rows of images show the dynamics of the southern and northern parts of the area, respectively.

Figure 13. A contour of the Krishna Delta showing areas of erosion and deposition during the period between 1977 and 2000.

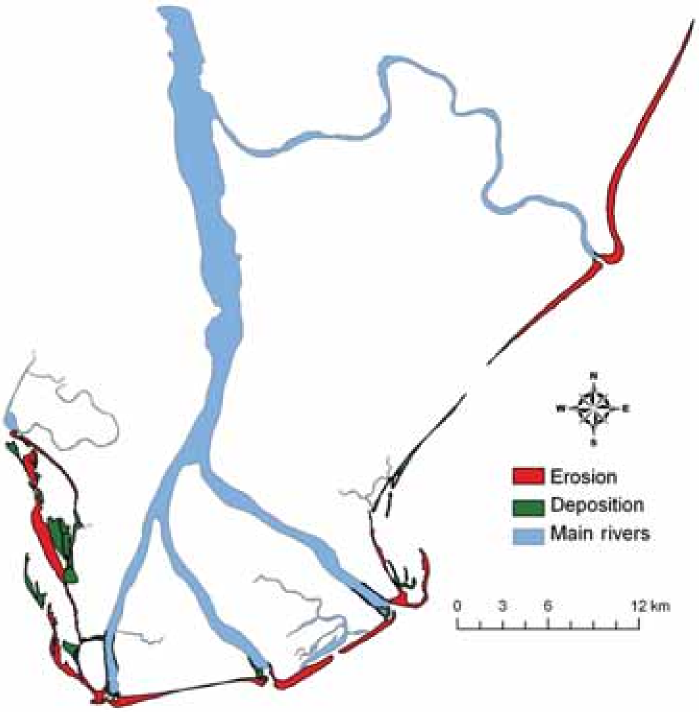


Table 4. Areal extent of erosion and deposition in the Krishna Delta over a period of 23 years (1977-2000).

Point #	Erosion (ha)	Deposition (ha)	Net Loss (ha)	Rate of Loss/Gain (ha/yr)
1	598	483	115	5.0
2	478	178	299	13.0
3	275	31	243	10.6
4	326	74	251	10.9
5	79	98	-19	-0.8
6	894	3	890	38.7
Total (23 Yrs)	2,650	867	1,770	77.4

The results suggest that while areas of predominant erosion and deposition interchange, the overall tendency is towards landward regression with losses of land to the sea - a situation similar to that in the Godavari delta. The annual net loss rate of 77.4 ha is almost the same as that in the Godavari delta (73.4 ha/ year; Malini and Rao 2004). One noticeable feature of the Krishna delta is its higher ratio of erosion to deposition (3.05 versus 1.6 in the Godavari) over the same period, which suggests that coastal erosion is more ‘effective’ in the Krishna delta than in the Godavari delta, despite the slightly smaller area (4,700 km2 versus 5,100 km2) and shorter shoreline of the former (134 versus 160 km). Erosion is also a dominant process through most of the coast line, while deposition is limited to certain sections only (Figure 13).

Possible Causes and Implications of Coastal Erosion

The regression of both the Krishna and the Godavari deltas cannot be explained by the sea level rise. Analysis of the available sea level data in the region for the period 1970-1996 (measurements at Visakhapatnam and Chennai) and for the period 1990-2001 (calculations from the daily tide gauge data at Kakinada to the north of the Godavari delta) did not reveal any significant rising or falling trends (Malini and Rao 2004). Therefore, coastal erosion in the Krishna and Godavari deltas can only be explained by the reduced sediment supply that is illustrated above, which, in turn, is due to upstream flow regulation. In addition, human activities in the delta regions (e.g., conversion of cropland and mangrove swamp areas into aquaculture ponds) may also be responsible for sea transgression, which in turn lead to coastal erosion and shoreline retreat of the deltas (e.g., Sarma et al. 2001).

Analysis of the longer sediment load data series for the downstream parts of the Krishna, and the use of more recent and more resolute remote-sensing images would result in a more detailed quantification of delta erosion. However, even with the existing limited data, it is possible to suggest that upstream basin storage development leads to the said retreat of deltas. The Krishna River is already effectively a ‘closed basin’ as only occasional high flows ‘spill’ into the delta with almost zero sediment contribution to it (Figure 8). Therefore, the storage that is already constructed in the Krishna will have a long-lasting detrimental effect on the delta and its agricultural productivity. (The situation in the Godavari delta will also most likely deteriorate after the construction of the additional storages planned as part of the NRLP).

Detailed sedimentation modeling studies would be useful in *all* major deltas of India in order to develop a better understanding and quantification of the links between upstream water and sediment flow reduction, and in terms of delta changes, between upstream storage growth and man-induced changes in deltas on the one hand, and between the erosion and retreat of deltas, on the other. Such studies could also specify the environmental flow releases that need to be made for the maintenance of delta sediment regimes.

Coastal erosion may be seen as a slow process, but it does entail few aspects which promote negative environmental impacts. One such impact is the salt-water intrusion. Bobba (2002) conducted a numerical modeling study of the Godavari delta and showed that saline intrusion may become a major factor of reduced agricultural productivity in that delta, due to increased groundwater pumping and reduce freshwater inflow (the authors could not identify a similar published study for the Krishna delta). Coastal erosion, caused by similar factors, facilitates salt-water intrusion deeper into the delta, adversely affecting land productivity. An additional factor, although highly uncertain in quantitative terms, is the potential sea level rise in the future 50 years due to climatic changes, although the limited available observations have not as yet detected it. This rise can lead to even more coastal erosion and deeper salt-water penetration, accelerating delta degradation. This research was not the scope of the current study and needs to be carried out as a separate and detailed project. While quantification of the above impacts will be developing, even limited environmental flow releases from existing reservoirs in the Krishna and the Godavari will delay the adverse environmental processes in both deltas. New storage reservoirs need to be planned in order to allow sediments to reach the deltas. Construction of the most downstream reservoirs however, particularly ones as large as Inchampali, will definitely not serve this purpose.

Conclusions

- All NRLP transfers are justified on the premise that ‘natural’ annual flow volume is exceeded 75 % of the time (e.g., 30 out of 40 years), and is available for water utilization. This does not consider the flow variability *within a year*, which is extremely high in monsoon-driven Indian rivers, and as a result, more water is perceived to be originally available at a site of transfer. Alternative techniques, based on low-flow spell analysis and, more importantly - storage-yield analysis may be used to re-evaluate the surface water availability at proposed transfer sites.

- All NRLP transfers are further justified on the basis of the maximum plans for irrigation (for 2025 or 2050), adopted by each state within each river basin. These plans boost irrigation requirements and serves as the driver for future water resources development. Maximum irrigation development is, therefore, effectively programmed into ‘India’s Water Future’ for the next half a century without alternatives or much discussion of its technical and economic feasibility

- A few points in Krishna (e.g., Almatti, Srisailam) are classified as ‘surplus’ points and are to become ‘Donors’. At the same time, some links (e.g., Bedti - Varada) are expected to bring water into the Krishna- upstream of the ‘surplus points’. Some ‘deficit’ points in lower Krishna can then rely on transfers from the Mahanadi through the Godavari, rather than on more naturally available water from the upper Krishna. It does not appear entirely logical to isolate subbasins and describe them as ‘surplus’, since they contribute differently to downstream water availability. There may be a need for more integrated water resources planning, whereby all future water transfers in and out of the same basin are considered and simulated together.

- The demands, which are currently considered in feasibility reports include irrigation, hydropower, industry and domestic use. It is suggested that at least an environmental demand for environmental management class D is also explicitly included at the planning stage – even as a contingency item. This class is the least acceptable from an ecological point of view, and requires a very limited environmental water allocation, in the range of 10-15 % of the long-term annual flow. This would be a precautionary measure in the absence of other more detailed information at present. However, it is envisaged, that even such minimal allocation will make certain transfer plans less feasible, as was illustrated in this paper. The main point, however, is that environmental water demand should be explicitly considered in water resources planning, similar to the water demands of agriculture, industry, hydropower and domestic needs.

- In this paper, for the donor and receiver points on the Polavaram- Vijayavada link, the environmental flow requirements have been calculated using the planning technique of Smakhtin and Anputhas (2006). These demands – as scenarios for two environmental management classes - have been used in the detailed water resources modeling of this link. The results of this modeling are described in a companion paper (Bharati et al. 2007).

- Locating reservoir sites (particularly as large as the planned Inchampali Dam) in the most downstream, normally flat, areas of river basins is problematic from an engineering perspective. Such reservoirs have large surface water areas that drastically increase evaporation and incur large dead volume, which reduces the active storage and makes the reservoir inefficient. They also capture most of the sediment supply to downstream deltas, which are the ‘rice bowls’ of India, due to the high land productivity. It has been demonstrated that the Godavari and Krishna deltas have been in retreat over the last 25 years, which is related, most likely, to reduced river flow and sediment flow to the deltas. Environmental flows need to be provided to at least partially arrest/delay this ‘shrinking of deltas’, which is currently threatening agricultural production and mangrove ecosystems, despite the slowness of the shrinking process.

- It is not possible to properly re-evaluate any plans without having the same starting conditions, i.e., the same hydrological data. Consequently only cautious statements can be made at present regarding the quantitative side of planned water transfers. However, no relevant and detailed hydrological data have been made available to this project despite the continuous efforts to obtain them. This leads to two more points. First, if these data are available (the actual NWDA flow time series for each donor/receiver point considered), it is possible to revise the estimates presented in this paper. Second, the continued policy of hydrological ‘data secrecy’ is not conducive to good water resources planning and development in India, and will not lead to socially and environmentally acceptable water projects. In fact, it is one of the major stumbling blocks on the way to scientific and engineering progress in water science in the country. India needs a centralized data storage and dissemination system. Such a system could be developed within the time frame of 2-3 years. However, policies of free data access could and should be reinforced before that. Without such reinforcement in data availability, it will remain difficult to resolve the water controversies in India.

Acknowledgements

The study forms part of the research project on the assessment of the National River Linking Plan (NRLP). The project is funded by the Challenge Program for Water and Food. Some of the Figures for this paper have been produced by S. Gunasinghe and M. Anputhas (both of IWMI-Colombo). Continuing data acquisition efforts by Dr. A. Gaur and Mr. K Anand (both of IWMI-India) are gratefully acknowledged. The authors are grateful to Dr H. Turral (IWMI- Colombo) and to Prof. T. McMahon (University of Melbourne, Australia) for constructive comments on this paper.

References

Agricultural Finance Corporation Ltd. 2005. Indirasagar (Polavaram): A multipurpose major irrigation project. Vol 1: Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP). Hyderabad, India.

Bharati, L.; Anand, B.K.; Smakhtin, V. 2007. Simulating water management scenarios for Godavari – Krishna inter-basin water transfer: The example of Polavaram-Vijayavada link. (in prep)

CWC- Central Water Commission. 2006. Integrated Hydrological Data Book (non-classified river basins). New Delhi, India.

Dams, Rivers and People. 2004. Vol. 1-2. South Asia Network on Dams, Rivers and People (SANDRP). www.narmada.org/sandrp

Bobba, A.G. 2002. Numerical modeling of salt-water intrusion due to human activities and sea-level change in Godavari delta, India. *Hydrological Science Journal*, 47 (S): S67-S80.

Inter-basin Water Transfer. 1999. Proceedings of the International Workshop. UNESCO, Paris, April 25-27, 1999. IHP-V Technical Documents in Hydrology. Document No. 28. UNESCO Paris.

Malini B.H.; Rao K.N. 2004. Coastal erosion and habitat loss along the Godavari delta front – a fallout of dam construction. *Current Science*, 87(9) 1232-1236.

McMahon, T.A.; Adeloye, A.J. 2005. Water Resources Yield. Water Resources Publications, LLC, Colorado, USA.

Sarma, V.V.L.N.; Murali Krishna, G.; Malini, B.H.; Rao, K.N. 2001. Landuse / land cover change detection through remote sensing and its climatic implications in the Godavari delta region. *Journal of Indian Society of Remote Sensing* 29: 85-91.

Smakhtin, V.U. 2001. Low-flow hydrology: a review. *Journal of Hydrology* 240 (3/4): 147-186

Smakhtin. V.U., Anputhas, M. 2006. *An assessment of environmental flow requirements of Indian river basins.* Research Report 107, International Water Management Institute, Colombo, Sri Lanka: IWMI.

In the Midst of the Large Dam Controversy: Objectives and Criteria for Assessing Large Water Storages in the Developing World

Zankhana Shah and M. Dinesh Kumar
International Water Management Institute, India Project Office, VV Nagar, India

Introduction

> *"We need large dams and we are not going to apologize for it. Those in the developed countries, who already have everything, put stumbling blocks in our way from the comfort of their electrically lit and air-conditioned homes… The Third World is not ready to give up the construction of large dams, as much for water supply and flood control as for power… Hydropower is the cheapest and cleanest source of energy, but environmentalists don't appreciate that. Certainly large dam projects create local resettlement problems, but this should be a matter of local, not international concern."*
>
> - Theo Van Robbroek, Former President of the ICOLD

The current crisis and urgency of meeting the food water requirements of the burgeoning world population has further aggravated the debate on 'dams or no dams'. The greatest opposition faced by dam-builders around the world is from the environmental (see D'Souza 2002; McCully 1996), financial, economic, and human rights fronts (see Dharmadhikary 2005; Fisher 2001; McCully 1996), whereas the proponents of large dams push their agenda on the grounds of enhanced food and drinking water security, hydropower generation, and flood control (see Braga et al. 1998; Verghese 2001; Vyas 2001). Both groups have reasons for their stances and chosen options to improve or alter the current practice of constructing large dams.

The latter half of the nineteenth century saw the birth of modern technology and engineering in the construction of large dams. The growth of dam-construction started in the developed countries holding technical know-how and financial resources, and later spread to the developing countries. By 1975, when the United States, Canada and the Western European countries had essentially completed their program of construction of large dams (Biswas and Tortajada 2001), the majority of the developing countries were either at the peak of their dam construction or were just starting to divert their financial resources towards it. As per the data offered by the International Commission on Large Dams (ICOLD), at the end of the twentieth century, China and India kept the United States far behind in the total number of dams constructed. According to the data, there are more than 47,000 large dams constructed all over the world and another 1,700 dams were under construction at the time of publishing this paper. The statistics of large dams presented by the ICOLD are debatable. The total number of large dams is based on the widely accepted and uniform definition of large dams, which considers ‘dam-height’ as the sole criterion. Such statistics on large dams, derived from such narrow technical criteria, if used as an indicator for assessing the extent of dam building a country has undertaken, can work against the larger developmental interest of many countries. While it is widely quoted that Asia has the greatest number of large dams in the world, many authorities are silent on how much water is being stored in these dams, and the extent of the area they submerge.

According to a database of the World Commission on Dams, dated the year 2000, which shows the distribution of dams across continents and regions, China has the largest number of large dams, followed by the rest of Asia, immediately followed by North and Central America. This can send shock waves through any ordinary person, leave alone the environmentalist, because of the fact that these regions with a high concentration of large dams are also the most densely populated regions in the world, with scarce arable land. But an ICOLD register on large dams, dated 1998, makes global comparisons on the basis of the volume of storage created by large dams and thereby brings out a totally different picture. Nearly 29 % of the total storage from large dams (6,464 km^3) is in North America and followed by South America (16 %). China with 10 % is only fourth in terms of volume of storage. The lack of a comprehensive and realistic criteria for defining ‘large dams’ invite unprecedented reactions from the environmental lobby on dam building based, with groups alleging that the statistics are misleading and that dam construction should be subject to stringent scrutiny for social and environmental costs. But the criteria of evaluating dam performance should change with the objectives.[1]

Limitations are also inbuilt in the methods used for benefit-cost analysis. The method identifies only those costs and benefits that can be assigned a market value. Thus, many costs and benefits remained unaccounted due to the difficulties in assigning them an economic value. Moreover, unprecedented costs and benefits are never considered, as revision of the cost-benefit analysis after 15-20 years of project completion is not a practice ever followed anywhere (see Biswas and Tortajada 2001). As many social and environment costs are therefore, not considered, many real benefits are underestimated or un-envisaged at the time of project planning. For example, a water resource planning exercise done in Gujarat, India has checked the possibilities and recommended the use of imported water from Narmada for recharge by spreading methods in the upper regional aquifers and riverbeds (GOG 1996 as cited in Ranade and Kumar 2004).

---

[1] If the objective is to assess the civil engineering capabilities of a country, then criteria such as design and foundation material and technology should be used for evaluation. Similarly, to assess the hydraulic design challenges for building large dams in this country, the spillway discharge, and storage capacity etc. can be used as the criteria. But if the objective is to quickly assess how centralized is our water storage, then the storage capacity criteria is good enough.

The Basic Premise

The authors take the position that the criteria used for defining large dams are not true reflections of the socioeconomic and environmental concerns prevailing in developing economies and, therefore, are not relevant. Part of the reason is the geographical spread of the large storage dams in the world. Food security and water security are extremely important concerns for these economies; submergence of productive land is a big concern, given the poor access to arable land; but the engineering challenges posed by the height of the dam are not so much a concern.

The definitions based on such poor criteria often invite unprecedented reactions from environmental lobbyists worldwide to subject dam-building proposals to stringent environmental scrutiny, and to revise the benefit–cost (BC) calculations integrating the social and environmental costs. The authors argue that, while there has been a lot of advancement in the recent past in the BC analysis of dam projects, these methodologies are still inadequate and fail to anticipate future social and environmental benefits that are likely to be accrued, resulting from the failure on the part of the proponents of dams to articulate these benefits. Some of the benefits are drinking water security, groundwater recharge, reduced cost of energy for pumping and so on. Often, dam-builders inflate certain components of the benefits and underestimate certain cost components, to pass the scrutiny of national and international environmental agencies. In the process, little attention has been paid to look at alternative ways of designing dams. Internationally, a lot of experiences now exist with designing dams in a way that can minimize the potential negative effects on society and the environment.

Objectives of the Study

The major objectives of this paper are as follows: 1) to illustrate the role of large storages in the context of development and economic growth, particularly for poor and developing countries; 2) to discuss the criteria used by various national and international agencies in defining large dams, and identify their limitations in the context of developing countries; 3) to evolve meaningful criteria for defining large storages, which adequately integrates the growing social and environmental concerns associated with dam-building; and, 4) identify the gaps in the current cost-benefit analysis and suggest new elements that adequately address (social, economic and environmental) sustainability considerations, and set out further new objectives and criteria for evaluating the impacts of large dams in developing economies.

Dams and Development: Controversies in Developing Countries

The Koran says, “By means of water we give life to everything.” Water is required as much as oxygen to sustain human life. Water gives life, wealth, and delivers people from diseases, and that is why, access to clean and safe water is one of the most basic human rights. However, the latest data released in the Human Development Report of 2006 reveals the minimal way in which this basic human right is met all over the world, largely in the developing and least developed countries. According to the report, one in every five people in the developing world

(11 billion in total) has access to an improved water source; dirty water and poor sanitation account for a vast majority of the 1.8 million child-deaths each year (almost 5,000 every day) from diarrhea— making it the second largest cause of child mortality; in many of the poorest countries, only 25 % of the poorest households have access to piped water in their homes, compared to the 85 % of the richest; diseases and productivity losses linked to water and sanitation in developing countries amount to 2 % of the GDP, rising to 5 % in sub-Saharan Africa—more than the amount that the region gets in aid; women bear the brunt of the responsibility for collecting water, often spending up to 4 hours a day walking, waiting in queues and carrying water; water insecurity linked to climate change threatens to increase malnutrition from 75–125 million people by 2080, with staple food production in many sub-Saharan African countries falling by more than 25 %.

The world's poorest countries are also the most water-scarce ones. This poverty to a great deal can be linked to water-scarcity. The gap in per capita water consumption is also huge between developed and developing countries. As per the Human Development Report of 2006, against the average consumption of 580 litres of water per person per day in the US and 500 litres in Australia, in India it's 140 litres per person, China it's 90 litres, Bangladesh and Kenya it's 50 litres, Ghana and Nigeria it's 40 litres, and in Mozambique it's less than 10 litres (HDR 2006). The threshold limit for per capita consumption is 50 liters (Glieck 1997; HDR 2006). Needless to say, these countries are not meeting even the basic human requirement of water. Besides, two out of every three persons in South Asia and sub-Saharan Africa lack even basic sanitation facilities. Reliance on groundwater is also not feasible without electricity and since no large-scale electricity generation is possible without water, the construction of large dams becomes inevitable.

Construction of large dams is opposed mainly on the grounds of the negative environmental impacts, and problems of displacement they cause, especially the subsequent impoverishment of the displaced people. Issues like 'drying up of rivers' and permanent destruction of the riverine ecosystem have been romanticized (see MacCully 1996; D'Souza 2002). There has been no appreciation of the fact that most of this water gets burnt up in the form of evapo-transpiration in producing food. The threats posed to the developing countries by the lack of clean and safe drinking water; food insecurity; economic and life losses due to droughts and floods; restricted economic growth due to the limited availability of water and power; have been shockingly ignored. On the other hand, the alternative models being advocated to improve water security for the poor, to boost food production and to meet their energy needs are proving to be rather fallacious.

It is important to remember that the negative environmental effects of dams can be controlled with good science and technology, and displacement of people can be turned into an opportunity for better livelihood by giving it a more humanistic face. But, the opportunity cost of delaying or stopping dam- construction could often be severe. There cannot be a better region in the world than sub-Saharan Africa to illustrate the effect of access to water on economic growth conditions. A recent analysis showed a strong correlation between rainfall trend since the 1960s and GDP growth rates in the region during the same period, and argued that the low economic growth performance of the region could be attributed to its long-term decline in rainfall (Barrios et al. 2004).

Such a dramatic outcome can be explained partly by governance failure, and the region's poor investment in water infrastructure. It is important to note here that sub-Saharan Africa has the lowest per capita water storage through reservoirs (HDR 2006). We will illustrate the significance of improving access to water by way of infrastructure through the subsequent paragraphs. The debate on the linkage between water and economic development is characterized by diametrically opposite views. While the general view of international scholars, who support large water resource projects, is that increased investment in water projects such as irrigation, hydropower and water supply and sanitation acts as engines of growth in the economy (see Braga et al. 1998; Briscoe 2005), the counterview suggests that countries would be able to tackle their water-scarcity and other problems relating to water environment only at advanced stages of economic development (Shah and Koppen 2006). The proponents of sustainable development believe that the ability of a country to sustain its economic growth depends on the extent to which its natural resources, including water, are put to efficient use through technologies and institutions, thereby reducing the stresses on environmental resources (Pearce and Warford 1993).

We take the position that developing countries need to invest in water infrastructure to improve their ability to boost economic growth and reduce poverty, apart from meeting food security needs. Before we begin to answer this complex question of ‘what drives what’, we need to understand what realistically represents the water richness or water poverty of a country. A recent work by Kellee Institute of Hydrology and Ecology, which came out with international comparisons on the water poverty of nations had used five indices, namely, water resources endowment; water access; water use; capacity building in water sector; and water environment, to develop a composite index of water poverty (see Laurence, Meigh and Sullivan 2003).

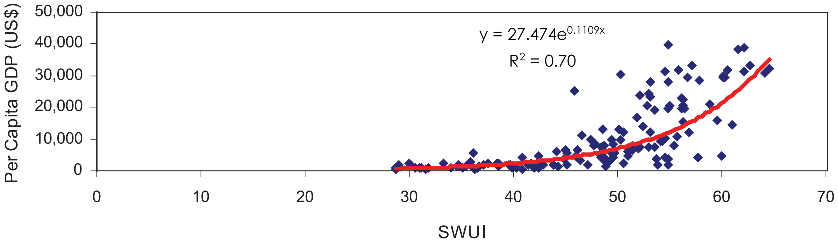
Among these five indices, we chose four indices to be important determinants of the water situation of a country, and the only sub-index which was excluded was the water resources endowment. This sub-index is more or less redundant, as three other sub-indices viz., water access, water use and water environment take care of what resource endowment is expected to provide. Our contention is that natural water resource endowment becomes an important determinant of the water situation of a country only when governance is poor and institutions are ineffective, which in turn adversely affects the community’s access to and use of water, and the water environment. That said, all the four sub-indices we chose have significant implications for socioeconomic conditions, and are influenced by institutional and environmental policy and, therefore, have a human element in them. Hence, such a parameter will be appropriate to analyze the effect of institutional interventions in the water sector and on the economy.

All the sub-indices have values ranging from 0 to 20. The composite index, developed by adding the values of these indices, is called the sustainable water index (SWI). It is being hypothesized that the overall water situation of a country (or SWI) has a strong influence on its economic growth performance. This is somewhat different from the hypothesis postulated by Shah and Koppen (2006), where they have argued that economic growth (GDP per capita), and HDI are important determinants of water access limitations and the water environment. The basis for deriving the new index is that the indices, viz., water access and water environment, do not capture all the dimensions of water use that are essential for development and growth. For instance, it is a truism that high levels of water use would be essential for maintaining high levels of economic growth, especially when countries are in their economic transition from agrarian to industrial. This is because water use for urban and industrial uses would go up exponentially in such scenarios.

It is essential to provide an anecdote for the counter-hypothesis that we propose. For this, we first take the fundamental question of what are the prime movers for economic growth, or what are the necessary conditions for sustainable economic growth. We already know that all the sub-indices of HDI have a strong potential to trigger growth in the economy of a country, be it educational status; life expectancy; or per capita income levels. When all these factors improve, they could have a synergetic effect on economic growth but the actual growth trajectory that a country takes also would depend on the country's macro economic policies, whether capitalist, or socialist or mixed. It is quite expected that in socialist economies, the income inequity along with per capita income would also be smaller. Against this, in a capitalist country, the income inequity as well as per capita income would be higher and this issue will be dealt with subsequently.

Now, worldwide experiences show that the improved water situation (in terms of access to water; levels of the use of water; the overall health of water environment; and enhancing the technological and institutional capacities to deal with sectoral challenges) leads to better human health and environmental sanitation; food security and nutrition; enhanced livelihoods; and greater access to education for the poor (based on UNDP 2006). This aggregate impact can be segregated with irrigation having a direct impact on food security, livelihoods and nutrition; and domestic water security having positive effects on health and environmental sanitation with spin-off effects on livelihoods and nutrition. If it is so, the improved water situation should improve the value of human development index, which captures three key spheres of human development namely, health, education and income status.

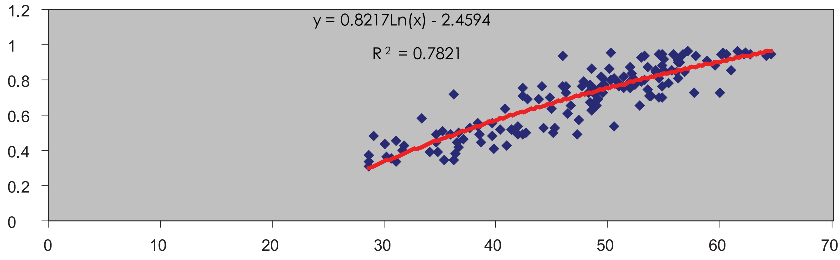
Figure 1. Sustainable water use index (SWUI) vs. GDP growth.



This means that the 'causality' of water as a prime driver for economic growth can be tested if one is able to establish a correlation between water situation and HDI, apart from showing the correlation between SWUI and economic growth. Regression between the sustainable water use index (SWUI) and purchasing power parity (ppp) adjusted per capita GDP for the set of 147 countries explains the level of economic development to an extent of 69 % (see Figure 1). We must mention here that Laurence, Meigh and Sullivan (2003) had estimated an R^2 value of 0.81 for WPI and HDI (*source:* Table 2: page 5; Laurence et al. (2003). Figure 1 shows that the relation between SWUI and per capita GDP is a power function. Any improvement in the water situation beyond a level of 50 in SWUI, leads to an exponential growth in per capita GDP. This only means that for countries to be on the track of sustainable growth, they need to put in place appropriate and effective institutional mechanisms and policies to improve the overall water situation that can result in improved access to water for all sectors of water-users and across the board; enhance the overall level of use of water in different sectors; to regulate the use of water, reduce pollution and provide water for ecological services; and to build technological and institutional capacities to tackle new challenges in all sectors of water use. Regression with different indices of water poverty against economic growth levels shows that the relationship between water availability and economic growth is not as strong as originally envisaged, meaning all aspects (water access, water use, water environment and water sector capacity) are equally important to ensure growth.

Subsequently, to test the causality, regression was run between *water situation* (expressed in terms of sustainable water use index (SWUI)) and HDI. This showed that HDI varies linearly with improvement in SWUI (Figure 2). This means, improvement in SWUI strengthens the basic foundations of economic growth. The R square value was 0.79. This is in spite of the fact that human development index as such does not include any variable that explicitly represents access to and use of water for various uses; overall health of water eco-system; and capacities in the water sector as one of its sub-indices. Now, such a strong linear relationship between SWUI and HDI explains the exponential relationship between sustainable water use index and per capita GDP as the improvements in sub-indices of HDI contribute to economic growth in their own way (i.e., per capita *GDP = F (EI, HI);* here *EI* is the education index, and *HI* is the health index).

Figure 2. Sustainable water index vs. HDI (selected).



On the other hand, if it is the stage of economic development that determines a country's water situation rather than vice versa, the variation in HDI should be explained by variation in per capita GDP, rather than that in SWU, in orders of magnitude. This is because there is already an established relationship between SWUI and HDI. We have used data from 147 countries to examine this closely. The regression between the two shows economic growth levels (expressed in per capita GDP ppp adjusted) explains HDI variations to an extent of 82 %). This is in spite of the fact that HDI already includes per capita income, as one of the sub-indices.

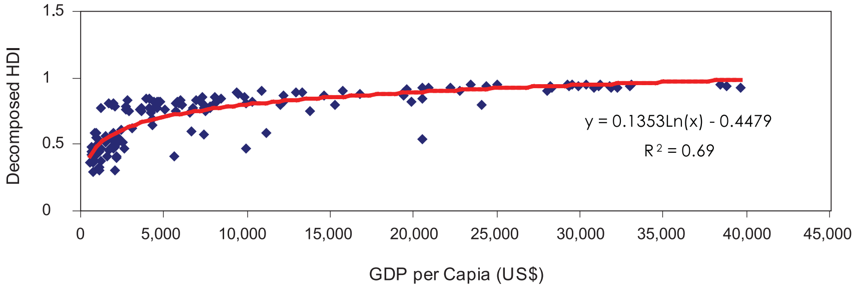
Hence, an analysis was carried out using decomposed values of the HDI index (after subtracting the GDP index). The regression value came down to 0.69 (R^2=0.69) with the decomposed index, which comprised an education index and a life expectancy index, and was run against the per capita GDP (Figure 3) against the 0.79 for the earlier case of GDP vs. HDI. This means that variation in the human development index can better be explained by the 'water situation' in a country, expressed in terms of the sustainable water use index, than the ppp adjusted per capita GDP. What is more striking is the fact that the relationship is logarithmic. Sixteen countries having low-value per capita incomes below 2,000 dollars per annum have medium levels of decomposed index. Again 42 countries having per capita GDP (ppp adjusted) of less than 5,000 dollars per annum have medium levels of decomposed human development index. As Figure 3 shows, significant improvements in HDI values (0.3 to 0.9) occur within the small range in the variation of per capita GDP.

The remarkable improvement in HDI values with minor improvements in economic conditions, and then ‘plateauing’ means that improvement in HDI is determined more by factors other than economic growth. Our contention is that the remarkable variation in HDI of countries belonging to the low-income category can be explained by the quality of governance in these countries, i.e., whether good or poor. Many countries that show high HDI also have good governance systems and institutional structures to ensure good literacy and human health, achieved primarily through investment in basic infrastructure including that of improving access to water. Most of these countries belong to the erstwhile Soviet Union (Armenia, Tajikistan, Kyrgyzstan, Uzbekistan and Georgia,) or are under communist regimes either in Latin America (Colombia, Nicaragua, Ecuador and Bolivia) or in Asia (Mongolia, China and Vietnam), which are known for good governance. Incidentally, many countries having highly volatile political systems and ineffective governance, characterized by corruption in government, are also extremely poor.

The foregoing analysis suggests that improving the ‘water situation’ of a country, which is represented by the sustainable water use index, is of paramount importance if we nee to sustain economic growth in that country. While the natural water endowment in both qualitative and quantitative terms cannot be improved through ordinary measures, the ‘water situation’ can be improved through legal, policy and administrative measures that support economically efficient, just and ecologically sound development and use of water in river basins.

The very fact that many developed countries had large water storage in per capita terms also strengthens the argument. The United States for instance, had created a per capita normal storage of 1,615 m^3 per annum created through 16,383 dams. In Australia, the 447 large dams alone provide a per capita water storage facility of nearly 3,808 m^3 per annum or a total of 79,000 MCM per annum. Aquifers supply another 4,000 MCM per annum. Against this, the country maintains a use of nearly 1,160 m^3 per capita per annum for irrigation, industry, drinking and hydropower, with irrigation accounting for 75 % of the use (*source*: www.nlwra.gov.au/atlas). China, one of the fastest growing economies in the world, has per capita water storage in the amount of 2,000 m^3 per annum through her dams.

Figure 3. Per capita GDP vs. decomposed HDI.



When compared to these impressive figures, India has a per capita storage of only 200 m^3 per annum. Ethiopia, the poorest country in the world, has a per capita storage of 20 m^3 per annum. But, there are many critiques against this argument based on per capita storage. According to Vandana Shiva, a renowned eco-feminist from India, the norms used for estimating per capita water use is fraudulent, and is a way to push through the large dam agenda by the World Bank. According to her, the many millions of ponds and tanks in the rural areas of India capture a lot of water and supply it to the rural population in a more democratic and decentralized way than the large dams do. But the contribution of such storage in augmenting the nation's water supplies is often over-estimated by environmentalists. In the case of Australia, the National Heritage Trust's report of the audit of land and water resources say, the many millions of farm dams in Australia create a total storage of 2,000 MCM per annum, against 79,000 MCM by large dams (www.nlwra.gov.au/atlas).

One could as well argue that access to water could be better improved through local water resources development interventions including small-water harvesting structures, or through groundwater development. As a matter of fact, the anti-dam activists fiercely advocate decentralized small-water harvesting systems as alternatives to large dams (see Agarwal and Narain 1997). Small-water harvesting systems had been suggested for the water-scarce regions of India (Agarwal and Narain 1997; Athavale 2003), and the poor countries of sub-Saharan Africa (Rockström et al. 2002). New evidence however, suggests that these systems cannot make any significant contributions in increasing water supplies in countries like India which have unique hydrological regimes, and can instead prove to be prohibitively expensive in many situations (Kumar et al. 2006). Also, to meet the large concentrated demands in urban and industrial areas, several thousands of small-water harvesting systems would be required. Recent evidence also suggests that small reservoirs get silted much faster than the large ones (Vora 1994), a problem for which large dams are criticized the world over (see McCully 1996).

On the other hand, the intensive use of groundwater resources for agricultural production is proving to be catastrophic in many of the semi-arid and arid regions of the world, including some developed countries like Spain, Mexico, Australia, and parts of the United States; and developing countries like India, China, Pakistan and Jordan. However, some of the developed countries like United States and Australia have achieved a certain degree of success in controlling the use of groundwater through the establishment of management regimes (Kumar 2007; Shah et al. 2004), which leaves engineering interventions[2] and their economic viability are open to question.

---

[2] Complex engineering interventions would be required for collecting water from such a number of small water harvesting and storage systems, and then transporting it to a distant location in urban areas.

Large Dams: History, Definitions and Recent Trends

History of Large Dam Construction and Technology Used

Construction of dams is a vital part of the history of civilisation. The earliest evidence of river engineering is found among the ruins of irrigation canals in Mesopotamia, which are over 8,000 years old. Remains of water storage dams found in Jordan, Egypt and parts of the Middle East date back to at least 3000 BC (World Commission on Dams 2000). Dam- building was continued into the time of the Roman Empire, after which the construction of dams was literally lost until the 1800s. Dams are a structure also seen in nature —beavers build dams to keep the water deep enough to cover the openings to their homes, protecting them from predators (www.arch.mcgill.ca). Table 1 gives a chronological list of dams constructed before the birth of Jesus Christ (BC).

Table 1: Chronological list of dam-construction.

Year Competed	Country	Name of	Type	Function	Purpose
3000 BC	Jordan	Jawa	Gravity	Reservoir	Water supply
2600 BC	Egypt	Kafara	Embankment	Reservoir	Flood control
2500 BC	Baluchistan	Gabarbands	Gravity	Reservoir	Conservation
1500 BC	Yemen	Marib	Embankment	Diversion	Irrigation
1260 BC	Greece	Kofini	Embankment	Diversion	Flood control
1250 BC	Turkey	Karakuyu	Embankment	Reservoir	Water supply
950 BC	Israel	Shiloah	?	Reservoir	Water supply
703 BC	Iraq	Kisiri	Gravity	Diversion	Irrigation
700 BC	Mexico	Purron	Embankment	Reservoir	Irrigation
581 BC	China	Anfengtang	Embankment	Reservoir	Irrigation
370 BC	Sri Lanka	Panda	Embankment	Reservoir	Irrigation
275 BC	Sudan	Musawwarat	Embankment	Reservoir	Water supply

Source: Schnnitter, 1994

The objectives of dam-construction were ranging from flood control to irrigation. As Altinbilek (2002) puts it, the construction of dams in the concept of water resource management has always been considered a basic requirement to harmonize the natural hydrological regime with human needs for water and water-related services.

The number, size and complexity of dam construction increased with the advancement of science and technology. The growth of large dams accelerated, especially during the nineteenth and mid-twentieth centuries. In 1900, there were approximately 600 big dams in existence. The figure grew nearly to 5,000 big dams by 1950, of which 10 were major dams. By the year 2000, approximately 45,000 big dams, including 300 major dams, had been constructed around the world (Khagram 2005). This was the time of population growth combined with industrial development and rapid urbanization. The acceleration of economic growth was not possible without the generation of power and availability of water for agriculture as well as for domestic consumption. Thus, dam-construction was a critical requirement for meeting the growth requirements of all other sectors. Current estimates suggest that nearly 30 - 40 % of irrigated land worldwide now relies on dams and that dams generate 19 % of the world's electricity (Bird and Wallace 2001).

Definitions of Large Dams

Numerous definitions are available of large dams, each serving a different purpose and objective, and, as such, are based on different criteria for evaluation. The definition followed by the National Inventory of Dams in the USA, is based on a dam's storage capacity. According to the Inventory, a dam is to be considered a large dam if it has greater than a 50 acre-feet storage capacity (www.coastalatlas.net). The U.S. Fish and Wild Life Service, under its Dam Safety Program, has adopted the following criteria for defining dams as small, intermediate and large (www.fws.gov). The structural height or the water storage capacity at maximum water storage elevation, whichever yields the larger size classification, is used to determine the size of a dam: 1) small dams are structures that are less than 40 feet high or that impound less than 1,000 acre-feet of water; 2) intermediate dams are structures that are 40 to 100 feet high or that impound 1,000 to 50,000 acre-feet of water; and 3) large dams are structures that are more than 100 feet high or that impound more than 50,000 acre-feet of water.

The Central Water Commission (CWC) of India, in its guidelines for safety inspection has given different definitions of dams on the basis of means of classification such as size, gross storage and hydraulic head. Against this, the Planning Commission of India has categorised all dams as large, medium and small irrigation schemes on the basis of the area irrigated. According to the Planning Commission, a large irrigation project is the one designed for irrigating more than 10,000 hectares (ha) of land.

The most recent, yet widely accepted definition of large dams is given by the ICOLD. The ICOLD defines a large dam as one having a dam wall above 15 m in height (from the lowest general foundation to the crest). However, even dams between 10-15 m in height could be classified as large dams if they satisfy at least any one of the following criteria (Rangachari et al. 2000). First, the crest length is more than 500 m. Second, the reservoir capacity is more than one MCM. Third, the maximum flood discharge is more than 2,000 m^3 per second. Fourth, the dam has complicated foundation problems. Fifth, an unusual design. The ICOLD definition has dam height as the major criterion for defining a large dam. Since this definition has been widely accepted, all the dams in the world are evaluated on the basis of this definition.

A Brief History of Dam Construction, Ideologies and Investments on Dams in India

Agriculture used to be and has remained the major source of employment in rural India. Hence, irrigated agriculture has always been on the list of high priorities for the state exchequer. The early Hindu texts, written around 800-600 BC, reveal certain knowledge of hydrological relationships. The Vedic hymns, particularly those in Rig Veda, contain many notes on irrigated agriculture, river courses, dykes, reservoirs, wells and water lifting structures (Bansil 2004). As per the historical review given by Rangachari et al. (2000) the Grand Anicut on the Cauvery was one of the earliest canal systems built, dating back probably to the second century. The authors have further mentioned that feeding water-deficit and arid regions with extensions from storage reservoirs was a widely accepted practice between 500 AD and 1500 AD. Tamil Nadu alone presently has over 39,400 such reservoirs built from the very early days. During the nineteenth century, India also experienced the benefits of the technology of high-head hydraulic structures. The British rule in India invested in renovations, improvements and extensions of earlier works along with new projects such as the 48 m high and 378 m long dam in the Periyar Project in 1886. The beginning of twentieth century had witnessed some of the ambitious projects of that time such as the Periyar and Peechipari dams in 1906, Krishnarajsagar Project in 1911, and the Mettur Dam in 1925.

At the time of independence in 1947, India was facing an acute shortage of food grain in sustaining her population. Investments in better irrigation facilities and improved agricultural technologies were imperative to achieve food sustainability. The Bhakra and Hirakud irrigation projects contributed significantly towards transforming India from a starving nation to an exporter of grains. Right up to the 1970s, large dams were seen as the synonym for development and economic progress. Dam-building reached its peak between 1970 and 1980, when an average of two to three new large dams per day were commissioned (Table 2).

Table 2: Large dams in India.

No.	Period	Number of Large Dams		
		15 m and more high	10 to 14 m high*	Total
1	Up to 1900	32	13	45
2	1901-1947	135	127	262
3	1948-1970	489	254	743
4	1971-1990	1,564	1,066	2,630
5	1991-2001	265	82	347
6	Data on time period not available	434	174	608
7	Total	2,919	1,716	4,635

Source: Data derived from the World Register of Dams, ICOLD

Note: * It includes dams for which heights are not known

Currently more than 80 % of the total water used in India is for irrigation. As per the estimates of the Ministry of Water Resources, India's water demand is going to increase three-fold by 2050, with increase in population and maturing of the Indian economy (Table 3). However, even then, agriculture would consume the highest share of water, as it would be burdened with a target of producing 420 Metric Tonnes (MT) to feed India's population (Verghese 2005).

These figures, indicating the number of large dams in India counted on the basis of dam height, can be extremely misleading to those who are concerned about the potential negative impact of large dams. The reason (why these numbers are misleading) can be better understood if we really look at the other aspects. For instance, the 2,920 dams having a height of more than 15 metres create a storage space of 296.29 BCM, with a mean storage space per dam to the tune of 101.5 MCM, whereas the rest of the 1,715 dams, which are also classified as large

Table 3: Sector-wise water consumption in India: Present and future scenarios.

Sector	Water Demand Projections			
	1990	2010	2025	2050
Irrigation	460 (88.6 %)	536 (77.3 %)	688 (73 %)	1,008 (70.9 %)
Domestic	25 (4.8 %)	41.6 (6 %)	52 (5.5 %)	67 (4.7 %)
Industries + Energy	34 (6.6 %)	41.4 (6 %)	80 (8.5 %)	121 (8.5 %) 143 (10.1 %)
Total (including others)	519	693	942	1,422

Sources: National Commission for Integrated Water Resources Development Plan; Ministry of Water Resources, 1999

dams, collectively create a storage space of 6.29 BCM only, with a mean storage space per dam to the tune of 3.65 MCM. This amount is equal to the volume of water pumped by 10 irrigation tubewells in a year or in other words, the water sufficient to irrigate nearly 365 ha of land, which means that these dams are not really large dams in any sense.

Further, the total storage created by all large dams (4,635 nos.) in India is only 302.58 BCM, with a mean storage capacity of 64.28 MCM per dam. This, however, does not mean that these dams actually store and provide that much water. The reasons are many. Firstly, many large dams in India do not get sufficient storage due to inadequate inflows from their catchments, whereas many reservoirs capture and release more than their storage capacity, as inflows are received at the time of releasing water. Second, the figures of storage capacity are of gross storage, and not live storage. The current total live storage capacity of reservoirs in India is only 214 BCM, and for many reservoirs, it is reducing due to silting as per recent sedimentation and siltation studies (Thakkar and Bhattacharyya, undated based on State Reservoir Survey data).[3]

Now, let us look at the figures for United States. The country has 16,383 dams, which are listed in the national dams register, and these include small dams as well, or dams having a height much less than 10 m. Of these 16,383 dams, only 1,735 dams have a height more than 15 m, and together they create a storage space of 140.14 BCM, with a mean storage space per dam to the tune of 80.8 MCM. But interestingly, the rest of the 14, 648 dams put together can provide a total storage space of 342 BCM, with a mean storage per dam to the tune of 23.3 MCM (*source*: the authors' own estimates based on US national dams register). This means that dams having a height less than 15 m, including those having a height much lower than 10 m, are very important storage systems for the US, as not only does the their total storage volume exceed that of large dams, but the mean storage volume per dam is also quite significant.

In Australia, the mean storage provided by a large dam is 176.7 MCM. In a nutshell, though India appears to be a champion in terms of building large dams, the actual figures of the water storage potential created by large dams is nowhere near that of countries like the United States, which have a lesser number of large dams (*source*: based on data provided in www.nlwra.gov.au/atlas).

---

[3] According to the data cited by the authors, the average live storage loss for the 23 reservoirs surveyed was 0.91% per annum, which in a nutshell means that the actual storage in these dams that can be diverted would be even less.

The Dam Controversy: Underlying Assumptions and Genesis

According to the definition evolved and followed by ICOLD, there are 4,635 large dams in India. All these dams are either 15 m in height or above, or fulfil any other criteria set by the ICOLD to qualify as large dams. In India and elsewhere in the world, the arguments of anti-dam activists become forceful and fierce when they simply magnify the 'negative impacts' of some very controversial dams with this figure and project those as the cumulative effect of all large dams. At the same time, it goes without saying that the pro-dam activists often tend to project the virtues of certain dams as having very good track records to further their cause of building more dams. Therefore, one needs to give a careful look to the details of the 4,635 dams listed in the ICOLD register before generalising the negative or positive impacts of dams on such a large scale.

With the kind of technical excellence achieved in the field of civil engineering and structural design, constructing a dam of 15 m in height or a dam with an unusual design or difficult foundation is not a big challenge any more. Besides, criteria such as the unusual nature of the foundation or complexity in design have not much to contribute towards environmental problems or achieving the targets of irrigation or economic growth. Any average number derived from a select group of few well-known or controversial dams on attributes such as irrigated area against submerged area, the benefit-cost ratio or number of people displaced against the number of people benefited should not be blindly extrapolated to get the cumulative effect of all the dams that are defined as large dams by ICOLD. Braga et al. (1998) point out the danger in using simple indices such as the area submerged per MW of electricity generated or number of people displaced per MW of power generated in the context of hydropower dams in Brazil, as these indices ignore the benefits from multiple uses of water. The primary reason for this is that complex factors—physical, climatic, technical/engineering, social, environmental, ecological and political—which govern the above said physical and socioeconomic attributes of dams, differ from case to case.

Unless relationships and trends are established on the basis of a large database, it would be difficult and often dangerous to draw inferences on any of those. Establishing such trends between the generally known attributes of dams and their social and environmental consequences is what we will be describing in the subsequent sections of this paper.

Analysis of the Criteria Defining Large Dams

Should the sheer number of large dams currently existing in different parts of the world, and those which are proposed to be constructed, really send warning signals on the magnitude of the costs being paid by society in terms of the negative consequences of dam construction on communities and the environment? To answer this question, it is crucial to know the usefulness or relevance of the criteria used for classifying dams as 'large'. The underlying premise is that most of the definitions of 'large dams' have been made or the criteria for classifying dams as large or small, evolved at times when large dam-building continued to pose major engineering challenges to humanity. For example, larger height meant greater foundation stresses and forces in the main body of the dam, posing geo-technical challenges; greater storage meant greater risk for people living in the downstream; and greater spillway discharge meant greater design challenges.

In a nutshell, these criteria never tried to capture the social and environmental imperatives of building dams. The driving force behind this analysis is the strong belief that the controversy of environment and mainly of displacement is critically rooted in the way large dams have been defined in the past and, therefore, really need a re-look, especially in the wake of growing social and environmental concerns in building 'large dams'.

None of the definitions mentioned above, including that of ICOLD, are universally applicable. The reason is that the different physical attributes of a dam, such as height, storage volume, and submergence area have different implications, and as such, no single component can be generalized to measure the various impacts generated by dams. The only criteria used by the Planning Commission of India in classifying dams as large, medium and small is the design command area.

On the other hand, the definition given by ICOLD has taken only dam height as a major criterion for defining large dams. When the impacts of dams are measured on the basis of this definition, ultimately it is only the dam height that is being considered. Other secondary criteria such as crest length, dam foundation or unusual design have no bearing in this fast developing world of technology, nor can reservoir capacity or flood discharge capacity logically substitute the dam height criteria. But height does not always share a direct relationship with factors like environmental impacts, displacement or even with total storage volume and submergence area.

Normally, dam designers use the storage-elevation-area curve to determine the appropriate height of the dam and spillway capacity etc. Depending on the topography of the location, the storage-elevation-area curve would change. In a deep gorge, the area under submergence of a high dam having a large storage volume may be very low. For example, the Idukki Dam, which is a double curvature arch dam, located in a deep gorge in the Idukki in Kerala-India, having a height of 555 feet may not have submerged much area, but its storage volume is 2,000 MCM. An analysis of the data of 9,884 dams from the World Register of Dams by ICOLD shows that the volume of water stored and impounded by a dam, which has implications for dam safety, has nothing to do with its height (Figure 4).

Further analysis with ICOLD data shows that the area of land submerged by the reservoir, which has both environmental and social impacts, such as the number of reservoir-affected people and deforestation, and loss of flora and fauna, has nothing to do with the height of the dam (Figure 5). While it is well known that the dam storage volume varies with elevation (height

Figure 4. Comparison of dam height with storage volume.

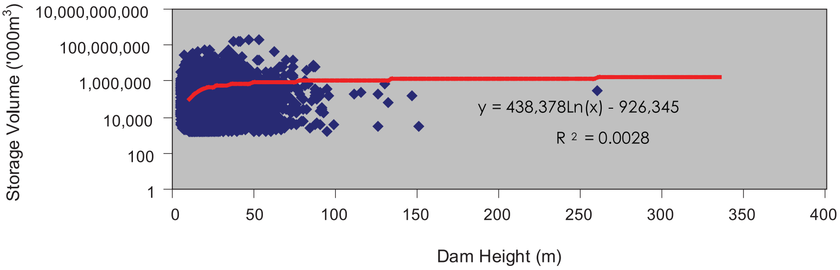
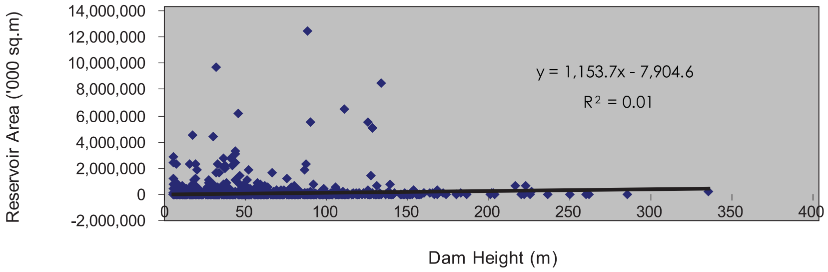


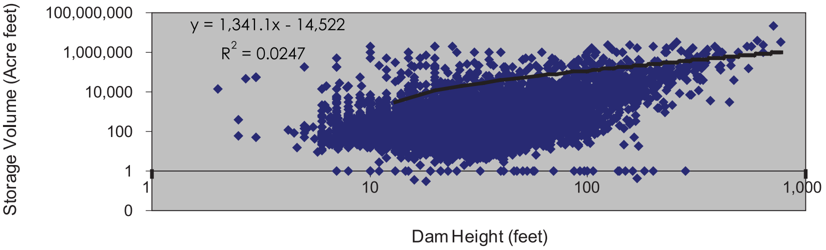
Figure 5. Comparison of dam height with reservoir area.



of the dam), which is in turn determined either by the topography of the area or the catchment's characteristics, the relevance of the above analysis is that it shows very clearly that dam storage volume varies drastically from location to location.

A similar analysis was performed for 16,638 dams in the United States, including small dams (as per ICOLD criteria), but showed no relationship between dam height and storage volume (Figure 6).

Figure 6. Dam height vs. storage volume for US dams.



The results emerging from the foregoing analysis had two major implications. First, they spawned concerns and protests from environmentalists the world over, on the engagement of poor and developing countries in dam-building on the basis of the sheer number of large dams that are ill-targeted. Second, they illustrated that the criteria currently being used by dam-builders and global agencies dealing with large dams, such as height and storage volume, are not true reflections of the changes dam-builders pose in an era of growing social and environment concerns.

Economic, Social and Environmental Impact-related Issues

Of the total 4,635 large dams in India, with either a height of more than 15 m or a storage volume higher than 1 MCM, 2,431 (more than 50 %) are built on local *nalla*, streams or *kotars*. Under such circumstances, some of them might be tank systems, with large surface areas, whereas certain others might be really big dams with either a large height or storage or both.

Also, it is most likely that they are constructed under various small-scale irrigation development schemes to achieve benefits at the local level. Thus, one needs to see whether they are storages created by dams or tanks before analysing their environmental impacts. Moreover, locally initiated water harvesting moves or even small-scale irrigation schemes do not usually face the problem of displacement, and their negative social impacts are also therefore, nil or very limited. In that case more than 50 % of India's large dams are socially and economically rewarding with minimum environmental cost bearing. In fact, their presence might have contributed towards the growth of vegetation, fisheries and water security.

The Environmental Impacts of Dams in India

The economic impacts of large dams in India are surmised as negative on the basis of construction cost overruns; poor performance of irrigation systems with heavy wastages due to poor conveyance efficiencies in the distribution system; negative downstream ecological impacts; preference for water-intensive and low-water-efficient crops; waterlogging and salinity in command areas; and the problems of overestimating of benefits because of the way non-availability of water and other ecological problems shrink command areas (see Rangachari et al. 2000). Very few studies really exist, which comprehensively evaluate the long-term economic and social benefits of large dams, and which show that any one of the dams had outlived its expected life span, but continued to give benefits in terms of food security, employment generation and power generation.

The criteria selected for impact evaluation also plays a major role in measuring the success or failure of dams. Part of the problem is that the same criteria, which was followed for evaluating costs and benefits at the time of planning the project, are used to analyze the dam impacts many years after they become functional. In the process, most of the benefit calculations overlooked some of the major benefits like food security coming from stable food prices, increased rate of employment in agriculture, improved fisheries, increased access to drinking water supplies, development and growth of processing and marketing units etc. The role of imported water in maintaining groundwater balance in irrigated semi-arid and arid regions was another un-intended impact that is much less appreciated by anti-dam activists. In many parts of the Punjab, well-irrigation is sustained due to the continuous return flows available from canal irrigation, which adds to the recharge.

This is not to argue that large dam projects were free of problems. Many of the dams, especially those built in semi-arid and arid regions, are over-allocating water from their respective basins. The irrigation agency is often keen to build over-sized dams, taking the flows of low dependability as the design yield, to inflate the design command and projected economic benefits. The amount of water that these dams are capable of capturing is much more than the amount of water their catchments generate, resulting in conditions of over-appropriation. This leads to reduced flows or no flows in the downstream parts of the river in most of the years causing ecological problems (Kumar et al. 2000; Kumar 2002). But such problems have occurred more due to inadequate governance of water in river basins, characterised by the lack of adequate scientific data for hydrological planning; piecemeal approach to water development; and ad hoc governance of irrigation systems (Kumar et al. 2000).

Objectives and Criteria for Assessing Large Dams

Objectives and Criteria for Classifying Large Dams

There are two sets of questions we are confronted with in this paper. First, do the current technical criteria used in classification of dams as ‘small’ and ‘large’, adequately capture the magnitude of the likely negative social and environmental impacts they can cause? If not, what should be the different criteria and considerations involved in classifying dams as small and large so that they are true reflections of the engineering, social and environmental challenges dams pose? Second, are the objectives, criteria and parameters currently used to evaluate the costs and benefits of large water impounding and diverting systems, sufficient to make policy choices between conventional dams and other water-harvesting systems or groundwater-based irrigation systems? Or what new objectives and criteria, and variables need to be incorporated in the cost-benefit analysis of dams in order to make it comprehensive?

On the first question, we have seen that the existing technical criteria used for classifying dams as large are too narrow, and do not capture the complex factors that govern the challenges posed by large dams, especially in an era when social and environmental concerns associated with development projects are very high. We have seen that the height of the dam, a major physical criterion used for classifying dams as large and small, does not have any bearing either on the area that dams submerge, which affects the environmental consequences of reservoir projects, or the storage that dams create, which can generate a negative impact like creating safety hazards or a positive impact in terms of hydrological and socioeconomic consequences. This takes us to the question of what should be the ideal criteria for classifying large dams.

From an environmental perspective, the area submerged by dams is a good indicator of the potential ecological damage that dams can cause, though the actual ecological consequences would depend on several factors, e.g., the nature of the eco-region where the dam is located. Such data are easily available for existing dams/reservoirs, or can be generated for the dams/reservoirs that are being planned. But, does that reflect some of the negative social impacts dams can cause? In that regard, one of the biggest challenges that developing countries are confronted with today is to minimize the number of humans displaced by the construction of dams, and thereby reduce the task of the government in rehabilitating and resettling such persons. This is a major issue because one of the positions taken by anti-dam activists is that the complete rehabilitation of ‘oustees’ is impossible. Further, this is an area where there is a limited availability of reliable data. Hence, choosing a physical criterion that adequately captures the two altogether different dimensions of the complex problem caused by dam-building becomes all the more important.

Anti-dam activists around the world have been using several different estimates of ‘displacement’ to build their case against dams. The following paragraphs illustrate this problem of how inadequate data create misinformation about an issue as vital as displacement. By identifying the right kind of criterion, and one which uses measurable indicators, for deriving the statistics of large dams helps us also assess the magnitude of the problems large dams pose in any country, by using the data available on such indicators.

Global estimates of the magnitude of impacts include 40 to 80 million people displaced by dams (Bird and Wallace 2001). In the case of India, no authentic figures are available for dam-induced displacement. Whatever numbers that are available are derived largely from rough calculations and have a stronger emotional base than statistics. Fernandes et al. (1989) claimed that India had 21 million people displaced by dams. Some years ago, the then Secretary, Ministry of Rural Development, Government of India, unofficially stated that the total number of persons displaced by development projects in India are around 50 million, and around 40 million of them are displaced solely by dams. This statement is a personal estimate without any supporting evidence.

Certain other estimates are based on average displacement per dam. After a study of 54 dams, The Indian Institute of Public Administration (IIPA) concluded that the average number of people displaced per dam was 44,182. Roy (1999) multiplied this figure with 3,300 dams in India (CWC estimates, as cited in Roy 1999) and received the figure of 145 million displaced persons. Since she felt this figure is too large, she took an average of 10,000 persons displaced per dam, and arrived at the figure of 33 million as the number of people displaced by dams. Singh and Banerji (2002) have compiled the displacement data of 83 dams with the aggregate of 2,054,251. The list covers dams constructed in 1908 as well as many dams under construction. Based on the submergence area of these 83 dams the authors estimated an average of 8,748 ha of land under submergence and the average displacement per ha as 1.51. While multiplying these two average figures with the total number of dams, which is 4,291 (as given by CBIP, nd01, p21 as cited in Singh and Banerji 2002), the authors obtained the astounding figure of 56,681,879 displaced persons.. The authors wish to mention here that this is a clear overestimation.

Now let us do a careful analysis of these figures. By mooting the figures of 21 million, 30 million and 40 million as the population displaced by dams, the experts refer to these figures as 2 %, 3 % and 4 % population of the country. This means that the government, researchers, volunteer organizations and even political parties have ignored or overlooked the problems of 4 % of the population of India until it was substantially addressed by Narmada Bachao Andolan (NBA) through their movement against the displacement of persons caused by the Sardar Sarovar Project. Let us analyze the flaws in the estimates that form the basis of many of the arguments against the construction of dams.

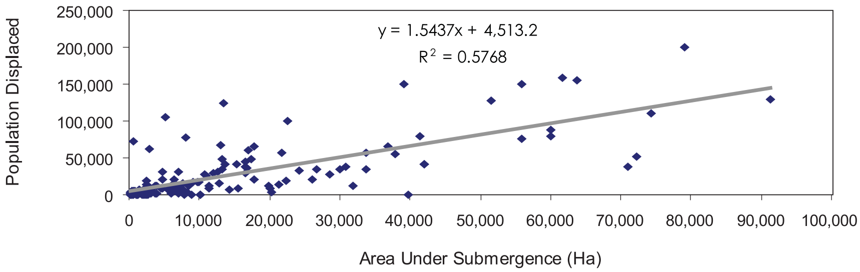
As per the National Register of Large Dams in India there are 1,529 large dams in the state of Maharashtra (CWC 1994), while according to the ICOLD figures there are 1,700 dams in the state. If we adopt Roy’s estimates of 10,000 persons being the average number displaced by a large dam, Maharashtra alone should have displaced between 15.29 and 17 million people. This is an exaggerated figure given that it is unlikely that such a big population of displaced persons in one state would not have gained more visibility i.e. given India’s poor track record for rehabilitation, the majority of such displaced persons should’ve been facing poverty and impoverishment On the contrary Maharashtra is India’s number two state as per the Human Development Index, next to Kerala (GOI 2006).

One of the major limitations of these estimates is that the majority of them are derived from the displacement averages calculated per dam, and are multiplied with the total number of dams. The figures offered by CWC, CBIP and ICOLD on the total number of large dams use ICOLDs definition as their basis. Thus, all the estimates of displacement have the inbuilt assumption that the height of a dam influences the magnitude of displacement. This perception that ‘higher the dam the larger the displacement’ is wrong, in that the increase in height of a dam at a specific location would increase the area under submergence, which thereby may cause an increase in the number of persons who are displaced.

It is a truism that theoretically, the population displaced would be largely determined by the submergence area and the population density of the region under consideration. But still it is important to know whether a strong relationship really exists at the operational level between the land area under submergence and the population displaced. This is in view of the vast variation in population densities from region to region in countries like India. The following figure supports the argument that land area under submergence is a good indicator. It is based on our analysis of 156 large dams in India and shows that the number of people displaced by dams increases linearly with the increase of the submergence area. Submergence area explains displacement to the tune of 58 %. The rest could be explained by variation in population density, and its effect on the displaced population. This is a high level of correlation and therefore, can be used to project the number of people displaced by dams, if we have data on the total area under submergence of all large dams.

The relationship also means that dam height is mainly location-specific, and as we have already seen that dam height does not have any bearing on either storage or submergence area., that it does not have a direct impact on displacement. The graph clearly shows that while 100 ha of submergence can cause the displacement of 150 plus people, what is important to note is that many large dams in India have a very low level of submergence. It should be noted here that in a country with a much lower population density (for instance, United States), the relationship would be different in the sense that the X coefficient would be much lower, meaning the number of people displaced by one sq. km of submergence would be smaller.

Figure 7. Submergence area vs. population displaced.



Now, the total area submerged by 2,933 large dams in India (obtained from Dams Register of India) was estimated to be 32,219.25 sq. km. The area submerged by 4,635 dams was extrapolated to be 49,660 sq. km (32,219*4,635/2,933=49,660). Based on this estimated submergence area and the formula given above, the total number of people displaced by dams was estimated to be at 7, 845 million. This is far less than the figures of displaced people provided by earlier researchers.

The main utility of this relationship is that once it is established for a given population density range on the basis of existing database, the number of people likely to be affected by dams in any region having that population density range could be estimated with a reasonable degree of accuracy, if the extent of the area under submergence is known. A direct approach of estimating displacement based on submergence area and population density in each case would be cumbersome, as it is difficult to get the population density data for very small areas.

In the developing world of today, the proximity of dams to fragile and rare eco-systems etc. could be one of the major criterions to assess the environmental challenge caused by the construction of dams. One major reason why the Silent Valley Hydroelectric Project in Kerala was abandoned in the late ‘80s was the fierce protests from environmental groups worldwide about the potential impact of the reservoir on rainforests, and the rare species of monkeys living in them. On the positive side, the geographical spread of large dams and how many of them supply water to naturally-water scarce regions are factors that illustrate the significance of dams in ensuring water security. These issues would be taken up for discussion in the next section.

Now, since it is true that height and storage volume together reflect the engineering challenges posed by dams, it can be inferred that a combination of parameters such as height, storage volume and submergence area would give a true reflection of the engineering, social and environmental challenges. Hence, the criteria for classifying large dams should be developed by taking into consideration all three of these important parameters collectively and not separately.

New Criteria for Evaluating the Performance of Large Dams

The arguments against large dams are largely on the environmental, economic and social fronts (MacCully 1996; D’Souza 2002). These arguments are founded more on emotional grounds rather than the scientific assessment of real marginal social costs and benefits, which forms the basis for an environmentally sound policy. The emotional ground is that the social costs caused by the development and use of water cannot be compensated by the increased economic benefits accrued from the use of water. This is in tune with the long-held position by Narmada Bachao Andolan that complete rehabilitation of communities displaced by dam construction is impossible. This is due to the deep-rooted belief that cheap and easy alternative options to building large dams do exist.

Internationally, such arguments gain a lot of credibility after the concept of virtual water trade was introduced in the early ’90s; and later on with small water harvesting options gaining acceptance. At least some of the environmental activists, who are against the construction of large dams in developing countries because of the displacement they cause, use the virtual water trade argument to contest the point that dams are important for improving food security. They instead argue that such countries should import food grain from water-rich countries. At the same time, the operational aspects of virtual water trade had not been studied. Recent research shows that globally, virtual water flows out of water-scarce regions to water-rich regions (Kumar and Singh 2005). In fact, many water-scarce regions in India export agricultural produce worth thousands of million cubic metres of water to regions that are water-rich (Amarasinghe et al. 2005; Singh 2004). Similar examples are found in China, Spain and United States. In a similar manner, local water harvesting solutions are found to be having extremely limited scope. This leads us to the point that the empirical evaluation of all direct and indirect costs and benefits of dams is inevitable, and the effort should be to minimize the social costs and maximize the returns from large dams, rather than looking at other options.

But responding to the war cry from environmentalists around the world, many international donors too have come out with criteria for evaluating the costs and benefits of large dams, which involve stringent environmental criteria. Environmental impact assessment (EIA) has been made mandatory for all World-Bank assisted dam projects in the world. But, the underlying premise in EIA is that all the environmental impacts associated with large dams are negative. The positive environmental effects of large dam projects such as their impact on the local ecology and climate are hardly examined (Kay et al. 1997).

During the past couple of decades, there were significant advancements in the methodologies used for evaluating the costs and benefits of dam projects. Hence, it is now possible to evaluate more accurately all future costs and benefits, including those which are social and environmental. But, such methodological advancements have also worked against the cause of dam-building around the world, as much less have been the advancements at the conceptual level in clarifying what should be considered as a positive effect or a benefit and what should be considered as a negative effect or a cost. This was compounded by major failures on the part of both the water resource bureaucracies as well as the environmental lobby to foresee all social and environmental benefits that are likely to accrue in the future from dam projects. This has led to a very unbalanced and biased assessment of all reservoir projects. We will be discussing these issues in the following paragraphs. First, one of the strongest criticisms against large reservoir projects by environmentalists was waterlogging and the salinity problems they can cause in the command area. Part of the reason for this is that nearly 50 % of the reservoir projects worldwide serve the purpose of irrigation. This has been an issue in many canal command areas of northern and north-western India and Pakistan Punjab. But, dramatic changes in agriculture in countries like India and Pakistan during the past 2-3 decades had converted some of these challenges into opportunities. With increasing groundwater draft for agriculture, which happened as a result of an advancement in pumping technologies, massive rural electrification, and subsidized electricity for well-irrigation, waterlogging is becoming a non-issue in many canal command areas that now have an improved groundwater balance. In Punjab, India, which is widely cited in literature as the ‘basket case of ill-effects of canal irrigation’, the area under waterlogging and salinity had actually reduced. One reason for this is the shortage of canal water, which had forced farmers to depend more on groundwater to improve the reliability of irrigation. In Gujarat, most of the areas that are likely to receive Narmada water are experiencing falling groundwater levels and, therefore, the threat of rising water levels due to induced water from canals does not exist.

While much attention has been given to the un-intended negative impacts or costs of dam/reservoir construction, such as water logging and salinity, downstream ecological damage, less consideration has been to identify, recognize or feel, the un-intended positive impacts such as drought proofing; drinking water security in rural and urban areas; increased biomass availability in canal command areas through energy plantation; and increased inland culture fisheries due to year-round access to water. This is a significant failure on the part of the pro-dam lobby, and the agencies concerned with dam- building.[4] Their performance is not evaluated in relation to the number of jobs these dams create in rural areas; or the increase in fishery

---

[4] One of the reasons for this has been the very sectoral nature of agencies involved, wherein the irrigation department, which is the primary dam-building agency in India, is pre-occupied with showcasing the benefits of irrigation expansion.

production; or the number of people benefited by the availability of drinking water, as each category of such information is privy to a different agency.

Let us now examine the unforeseen benefits. Almost all major dams in the world are constructed for hydropower (Altinbilek 2002). In many regions of the world, especially in Africa and Asia, the hydropower potential is huge and mostly untapped, and globally, nearly 19 % of all electric power is generated from hydropower. Hydropower is accepted as one of the cleanest source of power in the world and, as such, pursuing it as an alternative renewable source of energy to burning fossil fuels, is a great environmental benefit and one that has prompted discussions on multi-purpose dams.

Ideally, the negative externalities created by thermal and nuclear power on the environment could be treated as the positive externality that hydropower generation creates on society. So, a kilowatt hour of energy produced from a hydropower plant should give an additional benefit equal to the cost of environmental damage, which a thermal or nuclear power plant would cause for the same amount of power generated, and at higher levels of generation, the marginal social benefits (sum of positive externalities and economic benefits) would be much higher. The future of the energy economy in India and China, the two fast-growing Asian countries, is very much dependent on how they exploit their renewable energy resources like hydropower given that both countries have vast untapped hydropower potential. In India, most of it lies in north-eastern mountainous region and in the Western and Eastern Ghats. It would be quite logical to assume that India would construct more dams to generate more hydropower, in which case the discussions on the negative environmental impacts of dam construction would surely become null and void.

Large dams have an important role to play in replenishing groundwater resources and the water supply for domestic and industrial use. The return flows from canals had played a significant role in sustaining tubewell irrigation as well as sustaining agriculture during the years of water scarcity (Dhawan 1990). A recent analysis by Kumar (2007) showed that nearly 5 % of the deep tubewells, 10 % of the dug-wells and 5 % of the shallow tubewells in India are located in canal command areas. Unlike other parts of the world, where many large reservoirs are earmarked for water supplies, many large reservoirs in India are planned primarily for irrigation. But the real use of these reservoirs had diverted far from their planned use. India’s National Water Policy has set drinking water as the first priority over irrigation and industrial demand. During droughts, water from irrigation reservoirs gets earmarked for drinking water supply in rural and urban areas.

The Sardar Sarovar Project in Western India, for example, is expected to make a major dent in the rural and urban drinking water needs of 9,663 villages and 137 urban centres. Many dams in India are exclusively designed for drinking and domestic water supply, while numerous other dams originally meant for irrigation are now supplying water for domestic consumption. Without the Sardar Sarovar Project, the drinking water situation in these drought-prone areas would have been precarious in the absence of any sustainable source of water to meet the basic requirements (Talati and Kumar 2005) their residents. This is becoming a widespread phenomenon in India as many of her cities and towns are running out of water as a result of their local groundwater-based sources being exhausted by aquifer mining and permanent depletion (Kumar 2007). While NGOs, which advocate local alternatives in water management, especially in managing drinking water supplies, had fiercely opposed regional water transfers from Narmada to Saurashtra and Kachchh on cost grounds, they failed to set up demonstrations of such alternatives, which are effective in both the physical and economic front (Kumar 2004).

If health, ecology and environment were the major fronts on which large water projects were critiqued in the past, the future would increasingly find environmental, social and ecological reasons for their implementation (Vyas 2001; Kumar and Ranade 2004). Age-old arguments, such as water logging, salinity and downstream ecological impacts, which are still being used by the anti-dam lobby, would find little relevance in the present context. On the other hand, seepage from canals would help improve the groundwater balance over a period of time. The arguments about downstream ecological impacts primarily concern the potential reduction in lean season flows after impoundment. But, in practice, in large stretches between Indira Sagar and Sardar Sarovar, the flows are going to be regulated, and as a result there would be an increase in lean season flows.

The more immediate and positive ecological impacts would be accrued in water-starved regions where surplus flows from reservoirs can be diverted for ecological uses. The gigantic water transfer project in China involving a bulk transfer of water from the water-rich Yangtze River basin to seven provinces in the water-scarce north China plains could benefit more in terms of providing water for ecological flows in the Yellow River and meeting the drinking water needs of big cities like Beijing. The Yellow River had already dried up due to the heavy diversion of water for irrigation in agriculturally productive plains, and therefore, no water reaches the end of the river.

In Gujarat, western India, the Sardar Sarovar, being the terminal dam, can receive all surplus flows from the dams upstream and these surplus flows will be significant so long as upstream dams are not built. This water can be used to create induced flow in rivers in north and central Gujarat viz., Sabarmati, Watrak, Shedhi, Meshwo, Khari, Rupen, Sipu and Banas. There, rivers do not carry any flows for the entire year even in typical wet years and can therefore, receive the excess flows being diverted by Sardar Sarovar reservoir. This is already being practiced in the rivers of Central Gujarat. North Gujarat aquifers have high levels of salinity and fluoride at many places, which deteriorate the drinking water supply and causes major public health consequences (Kumar et al. 2001). The induced groundwater recharge can help to improve the quality of water by diluting the mineralized water in the aquifers, along with improving riverine ecology (Kumar and Ranade 2004).

While certain positive social, economic and environmental effects of dams were ignored or misunderstood, there are problems in the way the performance of dams are being evaluated by global interest groups. For instance, the criteria selected by the World Commission on Dams' (WCD) in its report, for evaluating dams are completion on time and completion within the budget (Perry 2001). Such technical and financial criteria often provide an unfair assessment of large dams. According to the author, criteria such as food availability, food security, food prices or even resettlement success are the right indicators to measure the economic performance of dams.

Food security is an important water management goal for many water-scarce countries including India and China (Kumar 2003; Kumar and Singh 2005). Food security is the central goal of constructing around 90 % of the large dams in India and other parts of Asia, while the ratio in Africa is 70 %. As per ICOLD data, worldwide, nearly 48 % of all large dams in the world were built for irrigation. Still, neither the dam-building lobby nor the irrigation agency has been successful in influencing the public debate to review dam performance on such social objectives as food security. While the positive externalities induced by the improved food security of regions and nations were less articulated in general, one particular reason for this has been the growing criticism that the surplus food India is producing is rotting in the godowns (warehouses) of the Food Corporation of India (FCI) and that dams therefore, do not lead to any improved access to food and, do not effectively contribute to food security at the domestic level.

Therefore, it is clear that the performance of dams should also be measured on the basis of food production and whatever additional purposes they serve. According to Bhalla and Mookerjee (2001), the total irrigation expenditure on major and medium irrigation schemes since independence in India has totalled Rs. 187,000 crore at 1999 prices. Against this, the total value of the agricultural output in 1998-99 was close to Rs. 500,000 crore. The authors have used these figures to calculate the internal rate of return (IRR) for big dams. As they have mentioned, depending on the assumptions one makes as to how much of the total investment for irrigation is investment for big dams (whether 100 % or 75 %) and depreciation rates (3 to 5 %), one obtains IRRs in the range of 3 to 9 %. Needless to say, without large dams, India would not have succeeded in feeding its burgeoning population. While what has been presented is just the direct economic benefit, the positive externality effects of dam-building should be added to it to get the social benefits as well. The benefits accrued from such positive externalities of increased food security benefits, should be assessed in terms of the opportunity cost of not producing that additional food internally, i.e., the cost of importing food. This is nothing but the import price of food grains minus the price at which they are available in the local market.

An IFPRI study attempted to examine the influence of Asian giants, China and India on international food prices by examining scenarios of rising cereal imports due to increasing meat consumption, which is a response to income rises and declining domestic production given the depletion of the natural resource base. The study used IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) to simulate a scenario of increased food imports by India to the tune of 24 million tonnes and China to the tune of 41 million tonnes in 2020 and showed an increase in international wheat and maize prices to the tune of 9 % and rice prices to the tune of 26 % (Rosegrant et al. 2001).

If we consider that half of the additional food grain production of the 94 million tonnes produced from irrigation in India since the 1950s, is from large dams (Perry 2001b), and if we decide to compensate through food imports the reduced production resulting from the absence of large dams, and we assume that prices would go up by just US$20/tonne (nearly 10 % of the current price), the imported portion alone would attract a total additional burden of 4,230 crore rupees annually. This is more than 1 % of India’s GDP. If we assume that the current domestic cereal prices are close to the import prices, the lower price consumers pay (say by US$20/tonne) is the impact of the domestic production of cereals on the food prices or the cost to the consumers and, therefore, can be considered as a positive externality effect of large dams. This whooping opportunity of cost of importing cereals itself seems to justify the large investment India had made in the irrigation sector. Such benefits should be added to the direct economic benefits to get the real social benefits of dam-building. This amount is the subsidy the government provides to the people by avoiding food imports and keeping the cereal prices in the local market under control.

The performance of irrigation reservoirs is often evaluated on pure engineering considerations, in terms of the area they irrigate against the total volume of water supplied; or the total amount of water consumed by the crop against the water supplied.

In addition to these, the irrigation bureaucracies in poor countries in Asia and Africa show an unwillingness to include the negative externalities as part of the project cost, as they do not like to transfer those costs to the water users, due to the fear that it would bring down the demand for water, and as a result would make benefit-cost ratios very unattractive. Instead, the practice is to bundle all such costs, and come out with a compensation package for the affected people, which is subject to scrutiny for economic viability by the donors.

This myopic tendency can be explained by the fact that the reduction in benefits, resulting from the decision to cut down the size of the project to minimize the negative effects on society, would be disproportionately higher than the reduction in cost. This can adversely affect B-C ratios. Hence, in an effort to get donor funds, the size of the project is stretched beyond the point where the net benefit becomes equal to net social costs through the exclusion of the negative externalities in cost calculations. This creates social ill-fare due to inequity in the distribution of project benefits. In other words, those who get the benefits do not bear the costs. Since the project agencies do not earn sufficient revenue from the services they provide, adequate attention is not paid to compensating those who are adversely affected by their projects. Such tendencies have also helped dam-builders in inflating the net benefits of the projects. If the donors make it mandatory for the dam-builders to include the economic value of negative externality effects in the project cost, it would have the following desirable consequences. First, the agencies would try and come out with innovative designs to reduce the marginal social cost of water development. Second, they would try and improve the quality of provision of water to raise the marginal value of the water. By doing this, even with lower level of development, the net social welfare from large dam projects could be enhanced.

In a nutshell, the criteria for evaluation of costs and benefits of dams needs to be made more comprehensive, taking into account all possible future ecological, environmental, economic and social benefits that dams are expected to accrue. For many developing economies, such benefits include: a) ecological benefits due to improved groundwater recharge through water transfers and canal return flows; b) economic benefits due to additional well-irrigation that is made possible with the availability of increased groundwater; c) greater drinking water security in drought-prone areas; and d) the environmental benefits of producing clean energy, which is made available through hydropower. Further, apart from economic criteria, large dams meant for irrigation should be evaluated in relation to the social criteria of how much they contribute in terms of improving regional and national food security, e.g., lowering food prices and making it accessible to most people. On the other hand, the negative externalities a large dam project creates should be included in the project cost, and be transferred to those who benefit from large dams in terms of the additional price they pay for the services that dams create.

Major Findings

1. Analysis of data from 145 countries shows that an improvement in the water situation of a country determines its degree of development and economic growth. The sustainable water index, which captures 1) access to water and the use of water; 2) water environment and human resource capacities in the water sector— seems to determine to a great extent the human development of a country, which in turn drives its economic growth. While the relationship between SWI and HDI is linear, that between SWI and per capita GDP is exponential. It is further argued here that building large storages would be crucial to improving the overall water situation of a country, against widely talked about alternatives such as intensive use of local groundwater resources and small-scale water harvesting.

2. Therefore, large dams are important for human development and the economic growth of a nation. This is also strengthened by the high per capita storage capacity achieved through dam-building by many developed countries such as Australia, United States, and fast growing developing countries like China.

3. The criteria used by ICOLD for classifying large dams, such as height and storage capacity, are not sufficient to capture the potential negative environmental and social consequences, for which large dams face opposition from environmentalists around the world. Analysis of data for 9,884 large dams around the world shows that the height of a dam neither determines the storage volume nor the amount of land submerged by reservoirs, which, in a way, imply the amount of safety hazards and the negative social impacts dams can cause. The use of such criteria results in an over-estimation of negative impacts like displacement, leading to over-reaction from the environmental lobby against the construction of large dams.

4. While India appears to be a world champion in building large dams in terms of the number of large dams built so far, the actual storage volume achieved by these dams is nowhere near those in the United States, Australia and China. While in the United States the mean storage per dam is (including those which are small as per ICOLD standards) is 80.8 MCM for large dams, and 28.8 MCM for small dams. Therefore, classification based on dam height neither indicates the potential benefits of dams nor their cost.

5. Analysis of data for 156 large dams in India shows that the number of people displaced by dams is a linear function of the total area submerged by them. Every one sq. km of area submerged by large dams in India displaces around 154 people. Using this formula, and the total estimated area of 49,660 sq. km area submerged by large dams, the total population displaced by large dams was estimated to be 7, 845 million persons. While the nature of the relationship between submergence and displacement will be the same for dams in other regions of the world, what might change is the number of people displaced per unit of submergence area according to the variation in population density. As shown by our analysis, while the area submerged by dams could be an

important criterion for deriving more reliable statistics about displacement, the available estimates of dam-related displacement in India are gross overestimates, in an order of a magnitude of eight more than the actual displaced.

6. In an era of the growing social and environmental concerns associated with building large dams, the criteria for classifying dams should be developed on the basis of three parameters, namely, dam-height, storage volume, and submergence area for them to truly reflect the true engineering, social and environmental challenges posed by them.

7. It is becoming increasingly clear that local water harvesting and virtual water trade options are non-existent in many countries, which need water for producing more food. This would compel water professionals to look for ways to minimize the social costs and maximize the returns from large dams. Apart from the economic cost of negative externalities on society in terms of human displacement and ecological degradation, the criteria for evaluating the costs and benefits of dams should involve considerations such as the impact of large dams on positive externalities associated with larger social and environmental benefits, such as stabilizing domestic food prices, reduced carbon emission for energy production, improvement in groundwater replenishment in semi-arid and arid areas due to imported surface water, and social security through improved access to water for drinking. A rough calculation shows that the benefit due to lower food prices (as a result of achieving a domestic production of 47 million tonnes of cereals, the approximate contribution of large dams to India’s food production) alone would be Rs. 4,290 crore.

8. Water and power development agencies in poor and developing countries are not willing to transfer the additional cost of water provisions due to the negative externalities on society, on to the beneficiaries of dams. They fear that the increase in cost and the resultant increase in prices that users would have to pay, would significantly reduce the demand for water, making it difficult for these agencies to justify the implementation of large projects. This helps them show high demand for water, thereby being able to build large dam projects. However, the marginal social cost of these dam projects often far exceeds the marginal social benefits they generate, causing negative welfare effects on the society. If the donors make it mandatory for the dam-builders to take into consideration the economic value of negative externality effects of dam building into the project cost, the net social welfare from large dam projects could be enhanced.

Conclusions

We have investigated mainly three issues in this paper: 1) The role of water in development and growth, and the role of large dams in particular; 2) does the current technical criteria used in the classification of dams as ‘small’ and ‘large’ adequately capture the magnitude of the likely negative social and environmental impacts they can cause? If not, what should be the criteria for classifying dams for them to be true reflections of the engineering, social and environmental challenges they pose; and 3) are the objectives, criteria and parameters currently used to evaluate the costs and benefits of large water impounding and diverting systems, sufficient to make policy choices between conventional dams and other water harvesting systems or groundwater-based irrigation systems and if not, what new objectives and criteria, and variables need to be incorporated in the cost-benefit analysis of dams so as to make it comprehensive?

Our analyses of data from 145 countries showed that for a country, improving the water situation, expressed in terms of the sustainable water index, can propel its economic growth, through the human development route. The analysis based on data for 9,884 dams across the world showed that the height of the dam does not have any bearing on the volume of water stored, the latter of which is an indicator of the safety hazard posed by dams. Further, the height of the dam has no bearing on the area of land submerged, the latter of which is an indicator of the negative social and environmental effects of dam construction. At the same time, the regression, using data on 156 reservoirs across India and representing different population densities, showed that a normative relationship exists between the number of people displaced by dams and the reservoir area. Therefore, it can be inferred that neither the dam height nor the storage volume alone are indicators of the negative social and environmental effects of dams. Instead, a combination of physical criteria such as height, storage volume, and the area under submergence needs to be considered for developing criteria for classifying dams.

Extrapolating the relationship between area under submergence and displacement of persons for nearly 4,635 large dams in India, showed that the available estimates of displacement in India could be ‘gross over-estimates.

Given the current reality that large reservoir projects have a significant positive impact on containing national food prices, providing clean energy, improving groundwater recharge in semi-arid and arid regions that are facing over-draft problems, and ensuring social security through the provision of water supplies for basic survival, the economic viability of these projects should be assessed in relation to the positive externalities they create on society and the environment. At the same time, the negative externality effects of large dams are often not transferred to the beneficiaries of the project, resulting in many negative welfare effects on society from dam-building. To avoid this, the donors should make it mandatory for dam- builders to include such negative externalities in the project cost so as to increase their accountability towards the communities that are adversely affected by dams. It is argued that such an approach will also increase the pressure on the dam-builders to come out with innovative system designs that minimize these costs, and raise the marginal value of water, thereby raising the net social welfare.

References

Agarwal, A.; Narain, S. 1997. *Dying Wisdom: Rise and Fall of Traditional Water Harvesting Systems,* Centre for Science and Environment. New Delhi, India: Centre for Science and Environment.

Altinbilek, D. 2002. The Role of Dams in Development. *International Journal of Water Resources Development* 18 (1).

Amarasinghe, U.; Sharma, B.R.; Aloysius, N.; Scott, C.; Smakhtin, V.; de Fraiture, C.; Sinha, A.K.; Shukla, A.K. 2004. *Spatial variation in water supply and demand across river basins of India*. Research Report 83. Colombo, Sri Lanka: International Water Management Institute.

Athavale, R. N. 2003. *Water Harvesting and Sustainable Supply in India*, published for Environment and Development Series, Centre for Environment Education, Jaipur and New Delhi, India: Rawat Publications.

Bansil, P.C. 2004. Water Management in India. New Delhi, India: Concept Publishing Company.

Barrios, S.; Bertinelli, L.; Strobl, E. 2004. Rainfall and Africa's Growth Tragedy, paper Presented at the Eighth Annual Conference on Econometric Modelling for Africa.

Surjit, B.; Mookerjee, A. 2001. Big Dam Development: Facts, Figures and Pending Issues. *International Journal of Water Resources Development,* 17 (1)

Bird, J.; Wallace, P. 2001. Dams and Development- An Insight to the Report of the World Commission on Dams, Irrigation and Drainage, 50. John Wiley & Sons, Ltd.

Biswas, A. K.; Tortajada. C. 2001. Development and Large Dams: A Global Perspective. *International Journal of Water Resources Development* 17 (1).

Braga, B.; Rocha, O.; Tundisi, J. 1998. Dams and the Environment: The Brazilian Experience. *International Journal of Water Resources Development* 14 (2).

Briscoe, J. 2005. 'India's Water Economy: Bracing up for a Turbulent Future', keynote address at the 4th Annual Partners' Meet of IWMI-Tata Water Policy Research Program, Institute of Rural Management Anand, February 26-29, 2005.

Central Board of Irrigation and Power. 1987. Large Dams in India Part-I, Central Board of Irrigation and Power, Government of India.

Central Board of Irrigation and Power. 1998. Large Dams in India, Part-II. Central Bureau for Irrigation & Power, Government of India.

Central Water Commission (CWC). 1987. CWC Guidelines for Dam Safety (revised), Central Water Commission, Government of India. http://203.199.178.89/damsafety/CWC%20Guide%20Lines.htm

Central Water Commission (CWC). 1994. National Register of large Dams, Central Water Commission, Government of India.

Dharmadhikary, S. 2005. Unravelling Bhakra: Assessing the Temple of Resurgent India. New Delhi, India: *Manthan Adhyayan Kendra.*

Dhawan, B. D. (ed.). 1990. *Big Dams: Claims, Counter Claims.* New Delhi, India: Commonwealth Publishers.

D'Souza, D. 2002. *Narmada Dammed: An Enquiry into the Politics of Development*, New Delhi, India: Penguin Books India.

Fernandes, D.; Fernandes, R. 1989. Displacement and Rehabilitation: An Estimate of Extent and Proejcts. In *Development, displacement and rehabilitation*, eds. W Fernandes, E. Fernandes and G. Thukral. New Delhi, India: Indian Social Institute.

Fisher, W.F.. 2001. Diverting Water: Revisiting Sardar Sarovar Project. *International Journal of Water Resources Development* Vol. 17 (1): 303-314.

Glieck, P. H. 1997. 'Human Population and Water: Meeting Basic Needs in the 21st Century'. In *Population, Environment and Development*, eds. R. K. Pachauri and Lubina F. Qureshi. New Delhi, India: Tata Energy Research Institute. pp. 105-121.

Human Development Report. 2006. Human Development Report-2006. New York, USA: United Nations.

Kay, M.; Franks, T.; Smith, L. 1997. *Water: Economics, Management and Demand*. London, UK: E & FN Spon.

Khagram, S. 2005. *Dams and Development: Transnational Struggles for Water and Power*. New Delhi, India: Oxford University Press.

Kumar, M. D.; Ballabh, V.; Talati, J. 2000. *Augmenting or dividing: Surface water management in the water-scarce river basin of Sabarmati.* Working Paper 147. Anand, India: Institute of Rural Management Anand.

Kumar, M. D.; Singh, O. P.; Singh, K. 2001. *Groundwater depletion and its socioeconomic and ecological consequences in Sabarmati river basin*. Monograph # 2. Anand, India: India Natural Resources Economics and Management Foundation.

Kumar, M. D. 2002b. *Reconciling Water Use and Environment: Water Resource Management in Gujarat, Resource, Problems, Issues, Strategies and Framework for Action*. A report submitted to Gujarat Ecology Commission for the Hydrological Regime Subcomponent of the State Environmental Action Programme supported by the World Bank.

Kumar, M. D. 2003. *Food security and sustainable agriculture in India: The water management challenge.* Working Paper 60. Colombo, Sri Lanka: International Water Management Institute.

Kumar, M. D. 2004. Roof Water Harvesting for Domestic Water Security: Who Gains and Who Loses? *Water International* 29 (1).

Kumar, M. D. Ranade, R.; Joshi, A.; Ravindranath, R.; Talati, J. 2004. *Large water projects in the face of hydro-ecological and socio-economic changes in Narmada valley: Future prospects and challenges.* Discussion Paper for ITP 2004, IWMI-Tata Water Policy Programme, Vallabh Vidyanagar.

Kumar, M. D.; Singh, O. P. 2005. Virtual Water in Global Food and Water Policy Making: Is There a Need for Rethinking? *Water Resources Management* 19: 759-789.

Sullivan, C. A.; Meigh, J. R.; Giacomello, A. M.; Fediw, T.; Lawrence, P.; Samad, M. 2003. The Water Poverty Index: Development and application at the community scale. Natural Resources Forum, 27, 189-199.

Mc Cully, P. 1996. *Climate Change Dooms Dams, Silenced Rivers: The Ecology and Politics of Large Dam*. London, UK: Zed Books.

Pearce, D. W.; Warford, J. 1993. *World Without End: Economics, Environment, and Sustainable Development.* (Published for the World Bank) London and New York: Oxford University Press.

Perry, C. J. 2001b. World Commission on Dams: Implications for Food and Irrigation. *Irrigation and Drainage* 50: 101-107.

Ranade, R.; M. Kumar, D. 2004. Narmada Water for Groundwater Recharge in North Gujarat: Conjunctive Management in Large Irrigation Projects. *Economic and Political Weekly* XXXIX (31): 3498-3503.

Rangachari, R.; Sengupta, N.; Ramaswamy, R.I.; Banergy, P.; r Singh, S. 2000. Large Dams: India’s Experience. Final Report, prepared for the World Commission on Dams, Cape Town, South Africa: Secretariat of World Commission on Dams.

Rockström, J.; Jennie B.; Fox, P. 2002. Rainwater Management for Improving Productivity Among Smallholder Farmers in Rrought-prone Environments. *Physics and Chemistry of the Earth* 27 (2002): 949-959.

Rosegrant, M. W.; Paisner, M.S.; Meijer, S.; Witcover, J. 2001. 2020 Global Food Outlook: Trends, Alternatives, and Choices. A 2020 Vision for Food, Agriculture, and the Environment Initiative. Washington, D. C., USA: International Food Policy Research Institute.

Roy, A. 1999. The Greater Common Good. *Frontline* (16) 11. May. 22 - June 04. India’s National Magazine from the publishers of THE HINDU

Shah, T.; Scott, C.; Kishore, A.; Sharma, A. 2004. *Energy irrigation nexus in South Asia: Improving groundwater conservation and power sector viability*. Research Report 70, Colombo, Sri Lanka: International Water Management Institute.

Shah, T.; Scott, C.; Buechler, S. 2004, Water sector reforms in Mexico: Lessons for India’s new water policy. *Economic and Political Weekly* 39 (4): 361–370.

Singh, O. P. 2004. Water-intensity of North Gujarat’s Dairy Industry: Why Dairy Industry Should Take a Serious Look at Irrigation? Paper presented at the Second International Conference of the Asia Pacific Association of Hydrology and Water Resources (APHW 2004), Singapore, June 5-9, 2004.

Singh, S.; Banerji, P. 2002. Large Dams in India: Environmental, Social & Economic Impacts. New Delhi, India: Indian Institute of Public Administration (IIPA):

Talati, J.; Kumar, M.D. 2005. Quenching the Thirst of Gujarat through Sardar Sarovar Project. Paper presented at the XII World Water Congress, New Delhi, November 22-26, 2005.

Thakkar, H.; Bhattacharyya (undated) Reservoir Siltation: Latest Studies- Revealing Results, a Wake-up Call. Dams, Rivers & People. www.sandrp.in

Verghese, B. G. 2001. Sardar Sarovar Project Revalidated by Supreme Court. *International Journal of Water Resources Development* 17 (1): 79-88.

Verghese, G. C. 2005. Water and Environmental Sustainability. New Delhi,India: The World Bank.

Vora, B. B. 1994. Major and Medium Dams: Myth and the Reality. Hindu Survey of the Environment, Chennai, India: *The Hindu.*

Vyas, J. 2001. Water and Energy for Development in Gujarat with Special Focus on the Sardar Sarovar Project. *International Journal of Water Resources Development* 17 (1): 37-54.

World Commission on Dams. 2000. Dams and Development: A New Framework for Decision Making. Earthscan Publications Ltd: UK.

Economic Performance of Public Investments in Irrigation in India in the Last Three Decades

Arlene Inocencio[1] and Peter G. McCornick[2]
[1] International Water Management Institute, Southeast Asia Region, Penang, Malaysia
[2]International Water Management Institute, Colombo, Sri Lanka

Introduction

The economic performance of Indian agriculture has been closely related to changes in agricultural productivity. Increases in agricultural productivity, in turn have been partly attributed to substantial increases in the irrigated area (Meizen-Dick and Rosegrant 2005; Gulati and Narayanan 2003; Vyas in Mundle et al. 2003; Pitman 2002). Agriculture accounts for over 80 % of consumptive water use in India (Pitman 2002), and is at times even recorded to be higher than 90 % (Amarasinghe et al. 2005; Meizen-Dick and Rosegrant 2005). The rise in the irrigated area came about with massive irrigation investments by the government, made with substantial support from the international donor community. These investments began in the 1960s and peaked in the 1980s, but in the early 1990s, public spending in agriculture slowed down and this translated into reduced spending in irrigation (Meizen-Dick and Rosegrant 2005; Gulati et al. 2005; Gulati and Narayanan 2003; Pitman 2002; Fan et al. 1999). Gross capital formation in agriculture declined from an average of 54 % in 1980-1981 to 26 % in 1999-2000 (Mundle et al. 2003). Support from multilateral and bilateral donor agencies also declined over the same period. However, there have been recent efforts to reverse this downward trend in investments in water-related infrastructure, including irrigation (Peacock et al. 2007; World Bank 2004).

The poor economic performance of many past irrigation projects in India may have contributed to the decline in irrigation investment and lending by international financial agencies in the 1990s (Meizen-Dick and Rosegrant 2005; Raju and Gulati 2005; Gulati et al. 2005; Pitman 2002; Jones 1995). Furthermore, the low rates of economic return may have also resulted in diminishing the poverty reduction impact of these irrigation projects (Meizen-Dick and Rosegrant 2005; Kikuchi et al. 2003; Rosegrant and Svendsen 1993).   These findings, however, do not suggest that governments should stop investing in irrigation because of the poor economic performance of such projects. This paper shows instead that there are ways to improve economic performance and that governments need not choose between achieving food security (or objectives other than getting high economic returns from projects) and investing in economically unviable irrigation projects.

The proposed river interlinking project will technically make more water available for consumptive and productive uses by diverting water from surplus to deficit basins. With agriculture as the biggest water user, increasing competing demands from other sectors and, the fact, that large proportions of the national and state budgets continue to be invested in the agricultural sector with apparently less growth and economically rewarding results, it is essential that agricultural water projects be well formulated and implemented to ensure greater efficiency and better overall performance including higher productivity.

To formulate better future irrigation projects in India, a comprehensive understanding of irrigation projects and their economic performance relative to those in other countries is important. Project performance is influenced by internal and external project factors, which could be a combination of physical, socioeconomic, institutional and policy factors. Among the internal factors are those that are related to formulation, design and implementation of projects. Specifically, costs of irrigation projects, agricultural productivity (yields and cropping intensity), operation and maintenance, and expected lifetime and gestation period of investments are the key factors. Some of the key external factors, which are beyond project control, are those that define the macro setting and policy environment (e.g., policies on pricing and tariffs for agricultural inputs and outputs and unforeseen changes in the market) of the country where a project is implemented.

This paper uses consistent data from 314 irrigation projects worldwide. The dataset includes 37 projects in India and a total of 91 projects in South Asia. The remainder is from 49 other countries in sub-Saharan Africa (SSA), the Middle East and North Africa (MENA), Latin America and the Caribbean (LAC), South East Asia (SEA), and East Asia (EA). The dataset contains certain key project characteristics and indicators of economic performance, which make it possible to systematically analyze irrigation projects and their performance. Using this dataset, this paper aims to: (1) examine the trends in the performance of irrigation investments in India, and contrast these with the trends in South Asia and the rest of the world; (2) determine the factors that influence the performance of irrigation projects worldwide; and (3) draw lessons for future irrigation investments in India.

This paper is constrained by the fact, that the dataset is based on projects that have been co-financed by the given country and an external funding agency. It does not include projects that were fully funded by a government or those which were solely funded by bilateral agencies. Furthermore, while the projects in the dataset include those with investments in groundwater and conjunctive water use, they do not consider the private investments in groundwater development, which have contributed significantly to the spread of irrigation in the past two decades in South Asia.

In the following sections, we describe the data, trends in economic performance and the profiles of irrigation projects. These are followed by a discussion of the results of a quantitative analysis of the performance of irrigation projects. The last section gives the conclusions and recommendations.

The Data[1]

This paper uses data obtained from various documents of irrigation projects funded by major international development organizations.[2] The project performance audit reports (PPAR) are the main source of data. In cases where the PPARs are not available, the project completion report (PCR) or the implementation completion report (ICR) are used as the next best source of information. In a few cases the staff appraisal reports (SARs), if available, are used to obtain further detailed information on project designs and project sites not cited in PPARs or PCRs.[3]

The dataset contains a total of 314 projects, which are all external funding agency assisted- projects with counterpart funding from recipient governments. A few projects received contributions from bilateral donors as well and a few others had farmers' contributions, but the latter are not quantified in project reports.[4] Of the total, 91 projects are in South Asia and 37 of these are in India. Table 1 gives the distribution of the sample projects according to purpose (new construction or rehabilitation). The total area irrigated by the 37 projects represents approximately 24 % of the 2001 official figure for net irrigated area in India, which is 55 million ha (GOI 2004).

The economic internal rate of return (EIRR) of an irrigation project reported at the project evaluation or completion is used as a measure of performance.[5] This measure is the sum of the discounted stream of benefits net of capital and O&M costs arising from the project. The EIRR is chosen as a performance indicator for two reasons: first, it is the most commonly used indicator of economic performance; second, in projects where no EIRRs are reported, it is possible to estimate them based on project outcomes described in the PCRs and the PPARs,

---

[1] This section draws from Inocencio et al. (2007). See Annex Tables 3 and 4 for the data definition and summary list of classifications.

[2] These development agencies are the World Bank (WB) African Development Bank (AfDB) and the International Fund for Agricultural Development (IFAD).

[3] The PPAR, ICR/PCR, SAR are standard documents prepared by international development agencies such as the WB, AfDB, IFAD, and even the Asian Development Bank at each respective phase of a project. A project cycle may begin with feasibility studies followed by a project appraisal (articulated in a formal document called the SAR) where a proposed project is submitted to the lending agency's Board for its approval, implementation (where an ICR/PCR is produced at the end), and evaluation several years after project completion (where a PPAR will then be produced).

[4] Annex tables 1 and 2 include the composition and the details of the projects selected from different regions.

[5] Among indicators to measure the performance of irrigation projects, the most convenient, if not the best, measure is the EIRR. Despite its advantages as a single measure readily available in project reports, Tiffen (1987) gives an account of its shortcomings.

Table 1. Five-year averages (%) and trends in economic performance (EIRR) of irrigation projects by purpose of project, 1965-1999[a]

	Total no. of observations	1965-1969	1970-1974	1975-1979	1980-1984	1985-1989	1990-1994	1994-1999	Time Trend (1965-99)[b]
Asia									
All projects		14	23	15	14	18	25	18	*ns*
	(177)	(6)	(15)	(49)	(49)	(28)	(27)	(3)	
New construction projects		14	18	16	11	11	19		*ns*
	(63)	(4)	(7)	(15)	(23)	(7)	(7)		
Rehabilitation projects		15	28	14	16	21	27	18	*ns*
	(114)	(2)	(8)	(34)	(26)	(21)	(20)	(3)	
South Asia									
All projects		0	18	19	16	17	26	14	*ns*
	(91)	(1)	(9)	(21)	(30)	(17)	(11)	(2)	
New construction projects			20	18	10	14	12		
	(32)		(5)	(7)	(14)	(4)	(2)		- *
Rehabiliation projects		0	14	19	21	17	29	14	*ns*
	(59)	(1)	(4)						
India									
All projects			19	25	14	13	11	14	- **
	(37)		(3)	(10)	(15)	(6)	(2)	(1)	
New construction projects			19	26	10	17	5		
	(20)		(3)	(4)	(9)	(3)	(1)		*ns*
Rehabilitation projects			25	20	9	16	14		
	(17)			(6)	(6)	(3)	(1)	(1)	
ALL REGIONS									
All projects		13	18	13	14	18	21	21	+ ***
	(314)	(11)	(24)	(75)	(86)	(56)	(53)	(9)	
New construction projects		13	14	12	12	12	18	24	+ *
	(126)	(7)	(14)	(31)	(37)	(18)	(14)	(5)	
Rehabilitation projects		13	24	14	15	20	22	18	+ *
	(188)	(4)	(10)	(44)	(49)	(38)	(39)	(4)	

Sources of basic data: Various project documents of the World Bank, African Development Bank and International Fund for Agricultural Development, various years

Notes: [a] The years indicate 'year of project start' rather than year of project completion. Note that projects began in early or mid 1990s were completed only in early 2000. The latest project completion date was 2004

[b] The time trend is a regression of EIRR over year of project star

'+' means the variable is increasing over time while '-' means a decreasing trend

***, **, and * indicate statistical significance of time trends at 1%, 5%, and 10% levels, respectively. *ns* stands for not significant. Figures in parenthesis are number of observations which is not the case for other performance ratings.[6] While this measure does not directly address poverty and livelihood objectives, it captures impact on incomes that should imbed poverty and livelihood considerations. Also, to the extent that appropriate and realistic amounts are allocated for O&M expenditures, this performance measure imbeds sustainability aspects of projects as well.

To examine the profiles of projects, each was classified according to its type, purpose, operation and maintenance, major crops grown, project size, project cost, average system size, year of project's commencement, donor appraisal and supervision inputs, time overrun, cost overrun, sizing error, and the relative complexity of the project.

The purpose of a project ranges from the construction of an entirely new project on a land previously not used for agriculture (also known as 'new construction with land opening') to purely rehabilitative purposes (known as 'rehabilitation) like rehabilitating existing projects. In between these two extremes, there are a number of sub-categories including 'new construction from rain-fed area', 'new construction + rehabilitation', and, where rehabilitation is the major component of the investment, 'rehabilitation + new construction'.

The type of project is based on a classification of the physical infrastructure used to capture and convey water. The six types used to classify this dataset are: (a) river-diversion systems without major storage capacity (river-diversion); (b) systems that use river water from dams that have major storage capacity (river-dam-reservoir); (c) tank (i.e., small reservoir) irrigation systems; (d) pump irrigation systems with water from river, pond or lake (river-lift); (e) pump irrigation systems with groundwater (groundwater-lift); and (f) drainage and/or flood control systems. In this last type, excess water is either drained or released from the land area in a controlled manner, with crops being grown on the residual moisture.

For operation and maintenance, the classification is divided into three categories, and they are: (a) entirely by government agency (government agency); (b) partly (usually the headworks and the main/primary canals) by government agency and partly (usually the distribution canals and below) by farmers' groups (government + farmers); and (c) by farmers alone (farmer-managed systems).

The categories for the major crops grown are: (a) paddy (paddy); (b) other cereals such as wheat and maize (cereals); (c) cash crops such as sugarcane and cotton (sugar/cotton); (d) perennial tree crops (tree crops); (e) vegetables (vegetables); and (f) fodder (fodder). This classification is based on the cropping system used in all regions represented in the dataset.

Project size is the total area irrigated by the project, and is the sum of newly constructed and rehabilitated areas, where relevant. An irrigation 'project' is often an aggregate of several 'systems' or schemes. About 20 % of the global sample irrigation projects in the dataset are

---

[6] Specifically, for the projects that do not report EIRR, we estimate it as the r that satisfies the following equation:

(1 + r) m K = S j=1n (R – c)/(1 + r) j,

where K = unit cost or cost/ha of irrigation construction/rehabilitation, R = return/ha due to irrigation construction/rehabilitation, c = O&M cost/ha, n = life time of the project (assumed 30 years for new construction projects and 15 years for rehabilitation projects), and m = average gestation period of investment.

'single system projects,' i.e., including only one irrigation system.[7] 'Total project cost' is defined as the total irrigation-related investment cost, including investment in both the physical irrigation infrastructure (e.g.,, dams, canals, sluice and measuring devices and roads) and software components (e.g.,, project management, engineering design, agriculture support and institution building).[8] 'Unit cost' is simply the cost of the investments divided by the project size.

The average size of a system is the area in a given project divided by the number of systems therein. The 'year project started' refers to the year in which implementation began, which could be a few months (or even years) after approval by the donor's board. Donor inputs for appraisal and supervision are the relevant personnel staffing effort in terms of weeks, which is not always available. The time and cost overruns are the differences between the actual construction period and costs, and those estimated at the time of project appraisal. The sizing error is the ratio of the difference between the planned and actual irrigated area benefited by the project, to the planned irrigated area, which is taken as a measure of the relative accuracy of the planning and appraisal stages. The number of project components listed in the SAR of a project is taken as a proxy to measure the complexity of the project.

Although our sample projects are all donor-funded projects, without exception the governments of recipient countries mobilize local funds for the projects. The share of government funds is the ratio of the local contribution to the total investment fund. While it would be more accurate to account for farmer contribution as well, most project documents do not quantify this. So, we accounted for this in the dataset as a binary (yes/no) variable. The share of software components is the ratio of the software costs, such as engineering management, technical assistance, agriculture support, research, training, and institutional development, to the total project cost. Conjunctive use of surface and groundwater is included as a yes/no binary variable. Data on the annual rainfall in the project area are usually provided in the SARs. Where no data are available in project reports, we obtained them from FAO AQUASTAT.

Conjunctive use of surface water and groundwater can mean greater water availability and reliability to farmers. A typical case of conjunctive water use in irrigation projects is found in many gravity irrigation projects, where farmers subsequently invest in pumps to supplement surface water from the systems. In our study, however, projects with conjunctive water use are defined as those that include it as a part of the project design. These projects account for over one-third of the global sample.

Two variables are introduced to capture the macroeconomic environments under which the sample projects are designed and implemented: 1) the real gross domestic product (GDP) per capita and 2) the purchasing power parity (PPP) ratio. For both variables, the averages from the project duration are used. The source of data for both variables is the World Bank Database (WDI Online). In the same manner as project costs, the real GDP per capita is expressed in terms of US$ at 2000 constant prices.

---

[7] The rest have more than one irrigation system per project. The number of irrigation systems per project varies significantly across projects. The medianis 6 systems in a project while the modeis one.

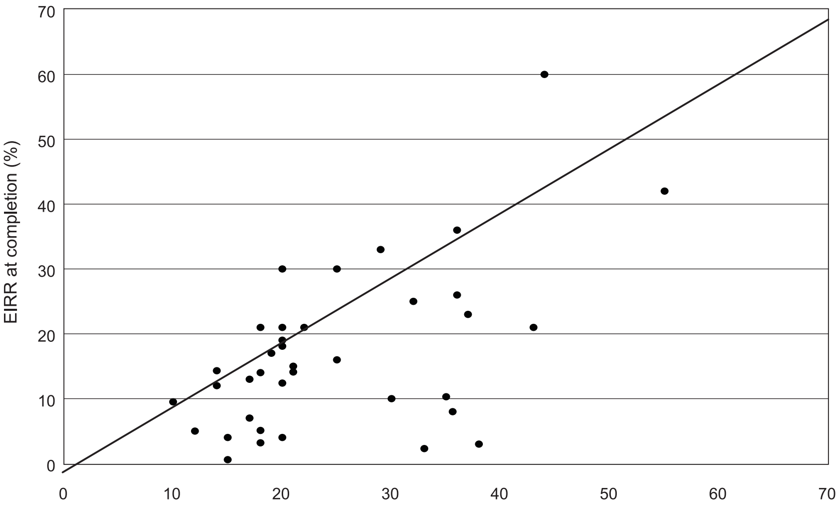
[8] Non-irrigation investment costs such as power generation and non-irrigation components in multi-sector projects are excluded. To make the cost data comparable across projects and over time, we measure the costs in US dollars at constant 2000 prices. When the costs are given only in local currency, we first convert them to current US dollars using the country's official exchange rate for the relevant years. The costs in current US dollars are deflated by the International Monetary Fund's implicit price index for world exports with year 2000 as the base.

Using this dataset and the classifications described above, we examine trends in performance and changing project characteristics over time in India and contrast this to the Asian and global samples.

Trends in Performance and Characteristics of Irrigation Projects

Figure 1 shows the plot of economic returns at appraisal (prior to implementation) versus the actual returns (at completion) for each of the 37 water development projects in India. This figure demonstrates that project appraisals have generally been over optimistic. Less than one fourth of the projects achieved or exceeded their target performance. If we consider the time trend of performance (Table 1), the actual economic returns for the projects in India have been on a significantly downward trend, more so in the case of recently implemented projects. The economic internal rates of return (EIRR) averaged 19 % in the early 1970s and only 14 % in the late 1990s. For rehabilitation projects, the economic returns started high in the 1970s and remained so even in the early 1980s, although the average declined substantially in the second half of the 1990s. It should be noted however, that during that 5-year period there was only one project in the dataset. The data showed a less significant decline for South Asia as a whole, and in the case of rehabilitation projects, the trend was actually positive, although like in India, projects completed in the latter half of the 1990s performed poorly. In this case, there were only two projects, and both were on rehabilitation. For all of Asia there is no significant trend in economic performance of irrigation projects with returns in investments remaining relatively high for all projects over time. In the case of India, the overestimation of economic returns at appraisal or lower completion/audit performance estimates is made worse by the decreasing EIRR trend. This observation is a cause for concern if we see it in the context of the global project sample, where performance is significantly improving over time both for new construction and rehabilitation projects.

Figure 1. Economic returns at appraisal and completion, India (n=37).



Irrigation Project Profile

Table 2 presents the distribution of the 37 sample projects from India and the changes in the profile of projects over time. Classifying according to the type of project shows that the entire sample for India is made up of single-purpose irrigation projects, while those from other countries include a few dual (with power components) and multi-purpose projects with irrigation components. As for purpose, the data show that new construction projects in India have been on the decline. The trends in this type of system show that both tank and groundwater-lift

Table 2. Five-year averages and trends in type of irrigation projects, India, 1970-1999[a].

Characteristics	70-74	75-79	80-84	85-89	90-94	95-99	Time Trend (1970-99)[b]
Type of project							
*Irrigation (%)	100	100	100	100	100	100	
Irrigation and power project (%)							
Multi-sector project (%)							
Purpose of project							
New construction with land opening (%)							
New construction from rain-fed farm (%)	67	10	40	33	50		*ns*
New +Rehabilitation (minor) (%)	33	30	20	17			- ***
Rehabilitation + New (minor) (%)		10		17			+ ***
*Rehabilitation (%)		50	40	33		100	*ns*
Type of system within a project							
*River diversion (%)		40	40	17		100	*ns*
River-dam-reservoir (%)	67	30	33	33	100		*ns*
River-lift system (%)							
Tank (%)			7	17			+ ***
Groundwater-lift system (%)		10	20	33			+ **
Drainage/flood control (%)	33	20					- ***
Type of O&M							
*Government-managed (%)	100	100	93				- ***
Jointly managed by government and farmers			7	17	100	100	+ ***
Farmer-managed system (%)							
Major crop irrigated							
*Paddy (%)	67	70	20	33	50	100	- *
Other cereals (%)	33	30	60	67	50		+ **
Sugar/cotton (%)			13				*ns*
Tree crops			7				*ns*
Vegetables							
Fodders							
Number of observations	3	10	15	6	2	1	37

Sources of basic data: Various project documents of the World Bank, various years

Notes: [a] Projects are grouped according the year the project started
[b] Linear time trend, estimated by regressing each variable over time (year of projection start)
'+' indicates a positive or increasing trend, '-'indicates a negative or decreasing trend
***, **, and * indicates that the trend is statistically significant at 1 %, 5 %, and 10 % levels, respectively. *ns* stands for not significant. The observation unit for trend estimation is the individual project for continuous variables and the 5-year average for dummy variables

systems are on the rise while drainage/flood control projects have significantly decreased. Consistent with the government's adopted policy of giving farmers increased roles in managing irrigation systems, the share of solely government-managed systems shows a negative trend while joint management by government and farmers is becoming the preferred mode of operation and maintenance (O&M). In terms of crops irrigated, while India is still predominantly irrigating paddy, there is a rising trend in the number of projects for other cereals and with paddy on the decline. In 1980-1984, there was a limited amount of crop diversification, with shifts into primarily sugarcane, cotton and tree crop, but no similar projects have been implemented since.

Table 3 presents the key characteristics of irrigation projects in India from the compiled project data. This table shows the size of projects in terms of total area irrigated, average size of systems

Table 3. Five-year averages and trends for key project characteristics, India, 1970-1999[a].

Characteristics	70-74	75-79	80-84	85-89	90-94	95-99	Time Trend (1970-99)[b]
Size/scale							
Project size (in terms of total irrigated area, '000 ha)[c]	133	322	352	265	112	2,300	+ **
Average size of systems within projects ('000 ha)[c]	133	92	60	12	47	1,150	*ns*
Number of project components	8	7	7	7	4	4	*ns*
Project financing							
Share of government fund in total investment cost (%)	71	51	44	50	39	56	- *
Farmer's contribution (% of projects with farmer contribution)	67	10			50		- **
Identification, formulation, planning factors							
Bank input for appraisal (staff weeks)	61	44	102	144	240	231	+ ***
Gestation period (months)	22	31	20	38	38	29	*ns*
Planned/actual irrig. area shortfall (%)	17	-70	6	-60	18		*ns*
Share of software component in total investment cost (%)	10	13	13	17	1	45	*ns*
Water availability/supply							
Annual rainfall (mm)	682	970	1,062	1,052	700	700	*ns*
Conjunctive use of water (% of projects)		60	33	17	50		*ns*
Implementation factors							
Bank input for supervision (staff weeks)	70	53	148	260	269	308	+ ***
Cost overrun (% to total investment cost)	80	12	2	15	19	-2	- *
Time overrun (years)	0.3	0.4	1.7	0.7	-3.0	-2.0	*ns*
Number of observations	3	10	15	6	2	1	37

Sources of basic data: Various project documents of the World Bank, various years

Notes: [a] Projects are grouped according to the year they started

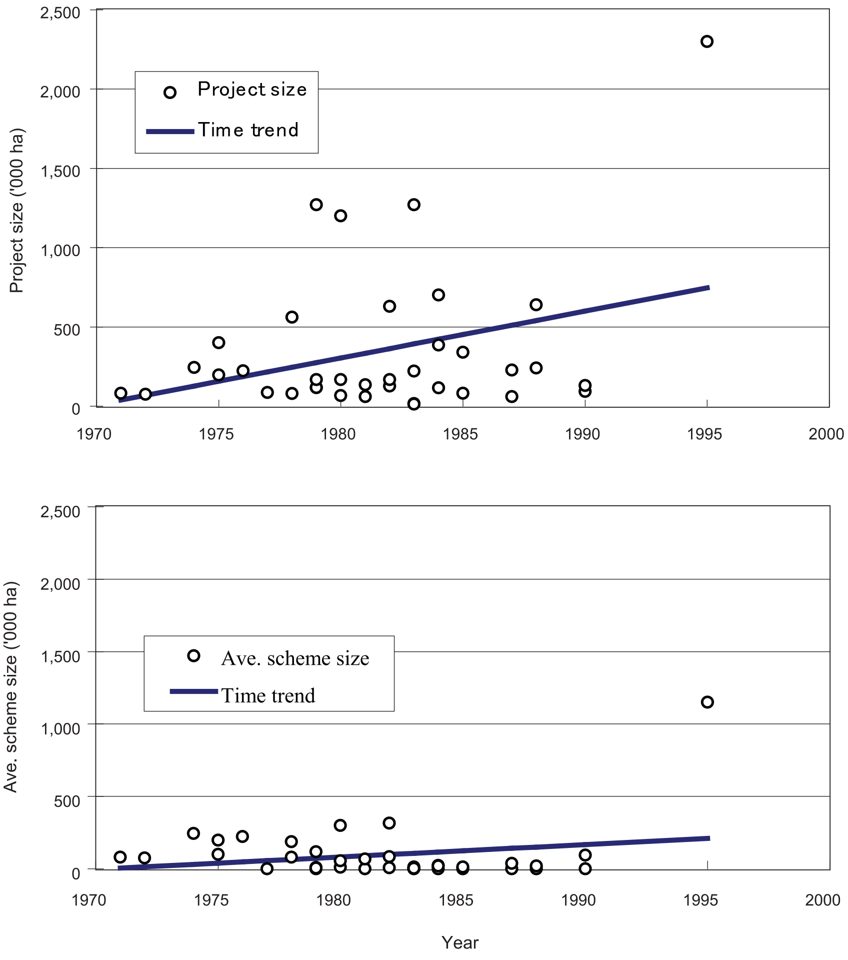
[b] Linear time trend estimated by regressing each variable over time (year of projection start); '+' indicates a positive or increasing trend, '-'indicates a negative or decreasing trend; ***, **, and * indicates that the trend is statistically significant at the 1 %, 5 %, and 10 % levels, respectively. '*ns*' stands for not significant. The observation unit for trend estimation is the individual project for continuous variables and the 5-year average for dummy variables

[c] Removing the Haryana Water Resources Consolidation Project in the project size time trend regression makes the positive coefficient insignificant. The effect on the average system size however, is the reverse, with the negative coefficient becoming statistically significant at 5% level of significance. That is, without the Haryana 1995 project in the sample, the project size is *not* significantly increasing over time while the average system size is significantly declining

within projects, project financing, design-related and implementation factors. The trend in 'project size' shows that irrigation projects in India have become significantly larger in the last three decades. Figure 2 clearly shows these trends. However, if the Haryana Water Resources Consolidation (HWRC) project, which has an extremely large total rehabilitated irrigation area, is excluded in the trend analysis, the time effect on 'project size' remains positive but no longer statistically significant. 'Average system sizes' on the other hand, have remained relatively constant but removing the HWRC project in the sample makes the decreasing trend for this variable significant. Projects do not appear to be getting more complicated with the number of components not evidently changing, as shown by the statistically insignificant time trend.

It is interesting to observe that over time, the contribution of the government to total project cost has steadily declined from a high average of 71 % in 1970-1974 to an average of about 45 % in the 1990s. The decline in government counterpart funding in irrigation projects is consistent with the decline in budget allocation for irrigation from the central government and irrigation expenditures of the states, especially since the 1980s. Gulati and Narayanan (2003) and Pitman (2002) also show the same trend. For the same period, and rather surprisingly, projects with farmers contributing to development are declining as indicated by the statistically significant

Figure 2. Trends in project size and average scheme size, India (n=37).



negative time trend. This is an unexpected trend given that elsewhere development agencies and governments are in agreement that farmers should be encouraged to share in the development cost of irrigation projects and thereby increase their sense of ownership of the project.

Among the planning and implementation parameters from which we obtained data, the donors' staff inputs for appraisal and supervision have significantly increased over time. More staff time was spent on projects in the 1990s than in the 1970s or 1980s with an average of about 60 staff weeks in the early 1970s to over 230 staff weeks in the late 1990s. In fact, not only are appraisal and supervision inputs increasing, they are substantially higher in India than in the sample irrigation projects elsewhere. The pattern for appraisal staff inputs could be a reflection of the desire of the external funding agency to ensure better quality projects, including more stringent environmental requirements. And the increase in staff inputs for supervision could result in more trouble-shooting or hurdles to overcome at the implementation stages.

Cost and time overruns are often cited as the key factors affecting project costs and expected economic returns (Pitman 2002, Jones 1995). The data show that for India, cost overruns have been significantly declining over time from a high average of 80 % in 1970-1974 to an average of 12 % in the 1990s. This observation implies that projects are completed within the originally approved or agreed budgets and yet we see the EIRR declining, suggesting that factors other than cost overruns must be influencing this decline in economic returns. No significant pattern is observed for time overrun, although World Bank's (WB) sector evaluations surmise that it is an important factor in overall project performance (Pitman 2002, Jones 1995).

For the Indian data there is no significant trend in the unit costs of the projects over time, while in the case of the rehabilitation projects in Asia and both rehabilitation and new projects in the global samples, the unit costs have been declining (Table 4). These trends may in part explain the relatively lower performance of the investments in India. Interestingly, Gulati et al. (2005), using data on capital costs for irrigation development projects in India from 1964-1965 and 1995-1996, show unit costs to have been increasing. The authors explain the rise in capital cost as due to exhaustion of easier or favorable sites and the shift to relatively more difficult ones, increased expenditures on rehabilitation and environmental protection, and leakage in capital funds (Gulati et al. 2005). The difference in trends between this study and that presented by Gulati et al. (2005) may be explained by the differences in the type of data used and the assumptions made in the calculations.[9] The state-level and India-wide annualized costs in Gulati et al. (2005) could be reflecting a number of state and country-related factors that are not captured in our data.

---

[9] Specifically, Gulati et al. used: (1) state-level and India-wide annualized costs of projects and in their project-specific analysis, examined in detail only three large projects which were started in the sixties and late seventies (Chambal Stage I in Rajasthan, Indira Gandhi Nahar Pariyojana Stage I and II (Rajasthan) and Upper Krishna Project in Karnataka) while this study uses project-level data and costs are not annualized for the 37 projects. The state and India-wide annualized costs are likely to include not only World Bank funded projects but also those which are funded by other donors and even those which could be fully funded by the states and the Government of India; and (2) basic data from various issues of the Combined Finance and Revenue Accounts of the Union and State Governments in India (CAG) which were then adjusted for inflation, gestation lag between the time of investment and completion of irrigation command areas and a social discount rate of 5%, while this study uses data from project performance audit or completion/implementation reports (PPAR or PCR/ICR) for each of the 37 projects which were then adjusted for inflation and converted to US dollars using the official exchange rates. This study did not adjust for gestation lag because it used both actual project costs and total irrigated areas at project completion.

Table 4. Five-year averages and trends in unit irrigation investment costs of projects by project purpose, UUS$/ha at 2000 prices), 1965-1999[a].

	1965 -69	1970 -74	1975 -79	1980 -84	1985 -89	1990 -94	1994 -99	Time Trend (1965-99)[b]
Asia								
All projects	3,278	3,159	3,398	5,037	1,350	1,168	2,822	*ns*
New construction projects	3,446	5,240	6,211	9,118	3,353	2,763		*ns*
Rehabilitation projects	2,942	1,338	2,158	1,427	682	609	2822	– ***
South Asia								
All projects	5,096	2,474	1,695	2,338	832	1,179	3,929	*ns*
New construction projects		3,019	2,782	4,283	1,357	4,310		*ns*
Rehabilitation projects	5,096	1,792	1,151	635	671	483	3,929	*ns*
India								
All projects		4,434	923	2,432	1,005	4,558	193	*ns*
New construction projects		4,434	1,649	3,775	1,486	7,421		*ns*
Rehabilitation projects			439	418	524	1,695	193	*ns*
All Regions								
All projects	3,527	3,589	6,593	5,960	3,703	3,605	5,120	+ ***
New construction projects	3,976	5,099	11,449	9,803	4,836	6,671	7,504	*ns*
Rehabilitation projects	2,742	1,476	3,172	3,058	3,167	2,504	2,139	– **

Sources of basic data: Various project documents of the World Bank, African Development Bank and International Fund for Agricultural Development, various years

Notes: [a] The year indicates 'year of project start' rather than year of project completion
[b] The time trend is a regression of log of unit cost over year of project start
'+' means the variable is increasing over time while, '-'means a decreasing trend
***, **, and * indicates statistical significance of time trends at the 1 %, 5 %, and 10 % levels, respectively
ns stands for not significant

Project Performance by Size of System

The sizes of projects and systems have been closely linked to performance. A number of reports strongly associated performance with the scale of either project or system (Inocencio et al. 2007; Pitman 2002; Jones 1995). Certain studies cited reviews of many failed large public irrigation 'projects' or poor performance of large-scale irrigation 'systems' (e.g., Peacock et al. 2007; Pitman 2002; Jones 1995).[10]

Focusing on the average size of systems within irrigation projects, the data do not support the above association of scale and performance. Table 5 shows that the differences in economic performance between major and minor systems or between medium and minor systems are not

---

[10] Jones cited earlier reviews of a number of World Bank funded large irrigation projects especially in the 1970s-1980s which performed poorly. These earlier assessments must have contributed to the pervasive thinking that large projects were generally failures.

Table 5. Economic performance of irrigation projects by scale (%), 1965-1999[a].

Characteristics	Major	Medium	Minor	Major vs. Minor[b]	Medium vs. Minor[b]
Asia					
All projects	18	12	18	*ns*	< (*)
	(110)	(14)	(53)		
New construction projects	14	3	14	*ns*	< (*)
	(40)	(2)	(21)		
Rehabilitation projects	20	14	20	*ns*	< (*)
	(70)	(12)	(32)		
South Asia					
All projects	17	16	19	*ns*	*ns*
	(49)	(6)	(36)		
New construction projects	13	-1	17	> (*)	
	(17)	(1)	(14)		
Rehabilitation projects	20	20	20	*ns*	*ns*
	(32)	(5)	(22)		
India					
All projects	16	22	18	*ns*	*ns*
	(26)	(2)	(9)		
New construction projects	13	-	21	*ns*	-
	(15)	0	(5)		
Rehabilitation projects	20	22	16	*ns*	*ns*
	(11)	(2)	(4)		
All Regions					
All projects	17	14	15	> (**)	*ns*
	(166)	(41)	(107)		
New construction projects	14	13	13	*ns*	*ns*
	(59)	(20)	(47)		
Rehabilitation projects	19	15	16	> (***)	*ns*
	(107)	(21)	(60)		

Sources of basic data: Various project documents of the World Bank, African Development Bank and International Fund for Agricultural Development, various years

Notes: [a] The years indicate 'year of project start' rather than year of project completion

[b] '>' indicates that on average, the first group has performed better than the second group

'<' indicates that on average, the second group showed better performance than the first group; whether the difference in averages between two groups are statistically significant is examined using the t-test for mean difference; statistical significance of the results are indicated by asterisks in parenthesis

***, **, and * indicate that the difference is statistically significant at the 1 %, 5 %, and 10 % levels, respectively

ns stands for not significant

statistically significant for India.[11] It is interesting to note that for Asia as a whole, minor systems are shown to have consistently done better than medium-scale systems. Quite in contrast, for South Asia's new construction projects, and for the global sample (except for the

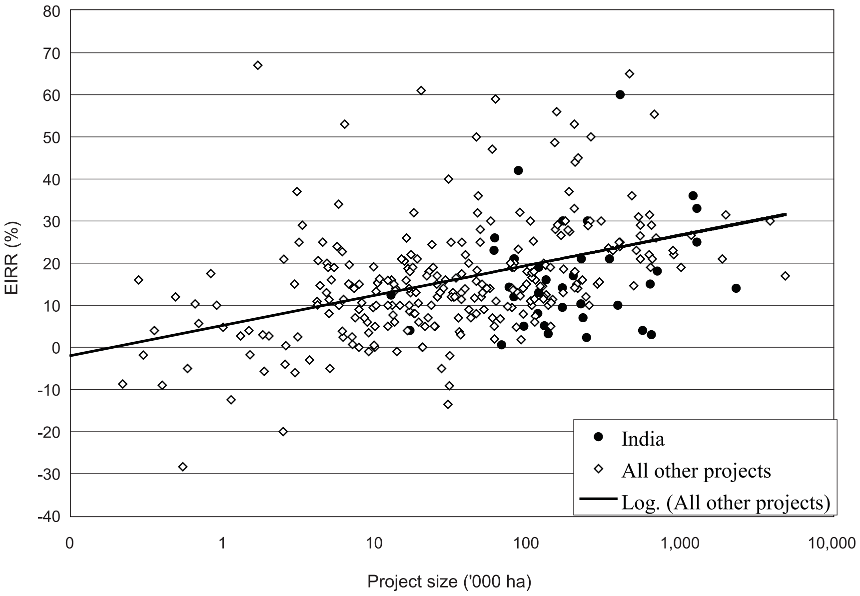
---

[11] We use the following definitions for scale of irrigation 'systems' (which are different from 'project' scale): a major system has an area above 10,000 ha; medium system has an area ranging from 2,000-10,000 ha; minor system has an area below 2,000 ha (Peter 2003).

new construction projects), major systems are shown to have significantly higher economic returns.[12]

On project size, Figure 3 shows that while a number of large projects have less than 10 % EIRR, larger projects obtained higher than 10 % EIRR. This pattern clearly holds for India's irrigation projects. So, the assertion that large projects are bound to fail cannot be supported by these data because small projects are more likely to perform poorly than large irrigation projects.

Figure 3. Project size and EIRR of irrigation projects, global sample (n=314).



Project Performance by Mode of Operation and Maintenance for Irrigation Systems

With governments devolving O&M responsibilities to farmers' groups a) to reduce their fiscal burden, b) increase the sense of ownership among farmers and c) improve viability and sustainability of projects — water user associations have been organized more aggressively during the past three decades. While many studies (e.g., Shah et al. 2002; Barker and Molle 2005) offer bleak pictures of the status and performance of these water user associations, Table 6 shows that for the India sample, no significant difference in economic performance is observed between jointly-managed and solely government-managed irrigation systems.

---

[12] As will be discussed in section 4 on the regression results, the higher economic returns for major systems are largely due to the fact that most large projects have large average system sizes which must be pulling up the average EIRR for major systems. When the impact of large 'projects' is isolated from the effect of 'average system size', minor systems are shown to do better than major systems.

Table 6. Economic performance of irrigation projects by type of O&M (%), 1965-1999[a].

Characteristics	Government-managed systems	Government and farmer managed systems	Farmer - managed systems	Government vs. Government+ Farmer managed systems[b]	Government+ Farmer vs. Farmer-managed systems[b]
Asia					
All projects	14	18	25	< (*)	< (*)
	(79)	(73)	(25)		
New construction projects	14	12	18	*ns*	*ns*
	(31)	(24)	(8)		
Rehabilitation projects	15	21	28	< (**)	< (*)
	(48)	(49)	(17)		
South Asia					
All projects	17	17	25	*ns*	*ns*
	(52)	(29)	(10)		
New construction projects	15	13	10	*ns*	*ns*
	(21)	(9)	(2)		
Rehabilitation projects	18	19	29	*ns*	< (*)
	(31)	(20)	(8)		
India					
All projects	17	14		*ns*	
	(32)	(5)			
New construction projects	16	5			
	(19)	(1)			
Rehabilitation projects	20	17		*ns*	
	(13)	(4)			
All Regions					
All projects	13	18	22	< (***)	< (*)
	(161)	(115)	(38)		
New construction projects	12	15	17	*ns*	*ns*
	(72)	(42)	(12)		
Rehabilitation projects	15	19	24	< (***)	*ns*
	(89)	(73)	(26)		

Sources of basic data: Various project documents of the World Bank, African Development Bank and International Fund for Agricultural Development, various years

Notes: [a] The years indicate 'year of project start' rather than year of project completion

[b] '>' indicates that on average, the first group has performed better than the second group

'<' indicates that on average, the second group showed better performance than the first group; whether the difference in means between two groups are statistically significant is examined using the t-test for mean difference; statistical significance of the results are indicated by asterisks in parenthesis

***, **, and * indicate that the difference is statistically significant at the 1 %, 5 %, and 10 % levels, respectively

ns stands for not significant

The same is true for South Asia. For Asia and the global sample of projects, the analysis shows that irrigation systems jointly managed by government and farmers' organizations have done better than solely government-managed systems. Also, solely farmer-managed systems are shown to have done better than jointly-managed systems, although there are no such systems in the Indian sample of projects.

Determinants of Performance of the Global Irrigation Project Sample[13]

The observations in Paper 3 provide adequate motivation to do further analysis on the performance of irrigation projects. Paper 3 uses trend analysis and comparison of mean values to show changes over time and similarities among sets of projects. A more systematic and robust analysis is required to properly establish the factors determining economic performance. An analysis of the global sample of 314 projects should help us gain broader insights on the performance factors. By making use of the full sample, India benefits from the experience and knowledge gained in irrigation investments in other countries and regions. The insights from such an analysis should be more retrospective while also forward looking, and should guide policymakers, implementors and development agencies in India in formulating a new generation of better performing and more viable irrigation projects.

The Regression Model

To explain the variations in the performance of irrigation projects, we apply the regression analysis, which determines the factors that influence economic internal rates of return (EIRR) of irrigation projects. The EIRR of the projects is the dependent variable regressed over a set of all the other variables in the dataset. To let our data 'speak for itself,' a Box-Cox model, which is the most flexible among linear regression models, is used. A general Box-Cox model for the EIRR analysis can be written as (Box and Cox 1964; Greene 2003: Ch.9):

$$Y_j^{(\theta_1)} = \alpha_0 + \sum\nolimits_{k=1}^{K} \alpha_k X_{kj}^{(\lambda_1)} + \sum\nolimits_{\ell=1}^{L} \beta_\ell Z_{\ell j} + \varepsilon_j \qquad (1)$$

where Y is the dependent variable (EIRR) subject to a Box-Cox transformation with parameter, θ_1, i.e., $Y^{(\theta_1)} = (Y^{\theta_1} - 1) / \theta_1$; X_k (k = 1, 2, …, K) are the transformed explanatory variables using a Box-Cox transformation with parameter λ_1, i.e., $X_k^{(\lambda_1)} = (X_k^{\lambda_1} - 1) / \lambda_1$; Z_ℓ (ℓ = 1, 2, ..., L) are the untransformed explanatory variables; and $\varepsilon \sim N(0, \sigma^2)$. Since the EIRR takes a non-positive value, the Box-Cox parameter for the dependent variable is assumed to be unity (i.e., $\theta = 1$).

The variables that are continuous and without non-positive values are selected for Xs, i.e., explanatory variables subject to the Box-Cox transformation. The rest of the explanatory variables are Z's, which are further divided into two groups. The variables in the first group, time overrun, cost overrun, and sizing error, are continuous variables with non-positive values, for which we assume $\lambda = 1$, i.e., the original linear form. The variables in the second group consist of binary dummy variables; 1 if applicable and 0 if not. For category variables from various typologies of projects, the variables which serve as the base or reference are omitted in the regression. These are: 'irrigation', 'rehabilitation', 'river diversion', 'government-managed system', 'paddy', 'South Asia' for the regional dummies, and 'WB' for donor dummies, respectively.

---

[13] This section draws from Inocencio et al. (2007).

From the Box-Cox equation, the elasticity of the EIRR with respect to a transformed variable is given as:

$$\frac{\partial(Y)}{\partial X_k}\frac{X_k}{(Y)} = \alpha_k\left(\frac{X_k^{\lambda_1}}{Y^{\theta_1}}\right) \qquad (2)$$

where X_k (k = 1, 2, 3… K) is a transformed explanatory variable. Similarly, the elasticity with respect to untransformed variables is given as:

$$\frac{\partial(Y)}{\partial Z_\ell}\frac{Z_\ell}{(Y)} = \beta_\ell\left(\frac{Z_\ell}{Y^{\theta_1}}\right) \qquad (3)$$

where Z_l (l = 1, 2… L) is an untransformed explanatory variable. The elasticities are evaluated at the mean for continuous variables and at unity for binary variables.

Estimation Results

Table 7 reports the EIRR regression results. Note that the elasticity is computed only for variables that have statistically significant coefficients. The regression shows that the following factors are significant determinants of the performance of irrigation projects: a) project size and average size of systems; b) number of project components which is a proxy for complexity

Table 7. Box-Cox regression and elasticity of determinants of economic performance of global irrigation projects, (n=314).

Explanatory variables	Regression coefficients		
	Coefficients	Test values	Elasticity
Transformed:			
Project size	5.113 ***	35.97	0.319
Average size of systems	-0.696 **	3.784	-0.043
Year project started	-2.009	0.792	
Bank input for supervision	-2.361 **	4.276	-0.147
Number of project components	-4.324 ***	8.889	-0.270
Share of government fund	0.680	0.192	
Share of soft components	0.656	0.831	
Annual rainfall	2.566 **	4.045	0.160
GDP per capita	-6.530 ***	10.20	0.181
PPP	0.537	0.756	
Untransformed:			
Time overrun	-0.218	0.406	
Cost overrun	0.237	0.028	
Sizing error	0.009	0.777	
Farmers' contribution	2.968 *	2.686	
Conjunctive use of water	2.900 *	2.811	
Irrigation and power	1.776	0.307	

(Continued)

Table 7. Box-Cox regression and elasticity of determinants of economic performance of global irrigation projects, (n=314) *(Continued)*.

Explanatory variables	Regression coefficients		Elasticity
	Coefficients	Test values	
Multi-sector project	2.428	0.699	
New construction w/land opening	-0.994	0.102	
New construction from rain-fed	-3.522 *	3.261	0.220
New + Rehabilitation	-0.108	0.003	
Rehabilitation + New	0.757	0.184	
River-dam-reservoir	2.344	1.875	
Tank	2.670	0.417	
River-lift	-2.702	1.437	
Groundwater-lift	1.258	0.249	
Drainage/flood control	0.254	0.011	
Government + farmer group	4.081 ***	7.523	0.255
Farmer-managed system	5.253 **	5.061	0.328
Cereals	1.019	0.306	
Sugar/Cotton	-1.797	0.480	
Tree crops	6.135 *	3.480	0.383
Vegetables	7.572 ***	6.120	0.472
Fodders	19.988 ***	9.603	1.247
AfDB	-4.051	0.980	
IFAD	-13.830 **	5.146	-0.863
East Asia	8.264 **	4.799	0.516
Southeast Asia	1.800	0.536	
Latin America & Caribbean	6.752 **	4.535	0.421
Middle East & North Africa	6.595 **	5.541	0.411
Sub-Saharan Africa	9.222 ***	10.16	0.575
Constant	17.192		
λ	-0.088	-1.350	
θ			
σ	10.314		
Log likelihood	-1178		
Number of sample	314		

Sources of basic data: Various project documents of the World Bank, African Development Bank and International Fund for Agricultural Development, various years

Notes: [a] Test statistics for regression coefficient follow the ÷2 distribution with the degree of freedom of 1, while those for the Box-Cox parameters follow the standard normal distribution

***, **, and *, indicate that the coefficients are statistically significant at the 1 %, 5 %, and 10 % level, respectively

[b] For continuous variables, elasticity is estimated at their means, and for binary variables, setting the variable unity

Elasticity is shown only for the variables that have significant coefficients

of projects; c) annual rainfall and conjunctive use of surface and groundwater, which are proxies for water availability; d) real GDP per capita, which is a proxy for a country's level of development; e) farmers' contribution to investment cost; and f) some design and technology factors.

Project Size and Average Size of System

The EIRR regression analysis reveals that project size, as measured by the total area irrigated by an investment project, is the most important factor determining the performance of irrigation projects. The larger the project size, the higher the economic returns. This result confirms an earlier finding of Jones (1995) that “big projects just do better than small projects.” From Inocencio et al. (2007), project size is shown as a critical determinant of the cost. The significant impact of project size on economic returns could be through its impact on project cost and the economies of scale effect.

The significant economy of scale of project size could be attributed primarily to engineering economies of scale in formulating and implementing irrigation projects (Inocencio et al. 2007; Jones 1995). Larger projects are supposed to attract better managers, and implementing agencies may have more incentive to be cost-efficient given the relatively higher profile and greater public attention (Jones 1995). In production processes, an economy of scale arises when there are indivisible inputs. Huge excavation machinery and dump vehicles for constructing dams and other physical irrigation structures are indivisible. More importantly, capable human resources, such as planners, design engineers, construction engineers, administrators, managers, contractors, consultants, government agency officials, foremen, and farmers’ organizations are all indivisible scarce resources that are indispensable in irrigation projects. The strong economies of scale in irrigation projects suggest the importance of these scarce inputs.

‘Average size of systems’ within irrigation projects has a significant performance-reducing impact. This result implies that the smaller the size of the irrigation system, the better the expected economic returns. One possible explanation for this seemingly contradictory result with the positive impact of project size could be the management advantage in smaller systems over larger ones. With potentially fewer farmers to coordinate within each system, smaller systems compared with large systems would be relatively easier to manage. That is, while economies of scale are very important at the project level, at the system (within each project) level better economic performance can be attributed to better management, which may characterize small irrigation systems (ADB-PEO 1995).

Some reports have argued that poor performance and success cases have been observed for both large and small irrigation projects (e.g., Rosegrant and Perez 1995; Brown and Nooter 1992; Adams 1990). They argue that scale appears to be less important in determining the success of the project than how it is managed. Our analysis indicates that, as far as the scale of irrigation projects is concerned, there are large economies of scale. However, it also suggests that at the ‘system’ or scheme level, how projects are managed appears to be more important than their scale.[14]

---

[14] If we take projects in the global sample with over 50,000 ha (an arbitrary ‘large’ project cut-off size) with a minimum of 100 systems (a relatively large number of systems) within each project and a maximum irrigation system size of 50 ha (an arbitrary ‘small’ system cut-off size), at least six projects in South Asia qualify for the ‘large project yet small systems’ category: four projects in Bangladesh (the Shallow Tubewell and Low-lift Pump Irrigation, the Deep Tubewell II project, Northwest Tubewell, and Shallow Tubewell project); and two in India (the West Bengal Agricultural Development Project and Minor Irrigation Project). Using this definition, other examples in South Asia and Latin America are a mixture of village irrigation, low-lift pump irrigation, rural development, national irrigation rehabilitation, natural resources management and irrigation development, and land-water conservation. Project sizes range from 11,000 to 46,000 ha while the corresponding system sizes range from an average of 8 to 35 ha.

As shown in Table 3, India's project size is significantly increasing over time while no pattern is established for the average system size. The increasing project size appears consistent with the regression result. However, removing the Haryana Water Resources Consolidation project from the sample, the increasing project size trend becomes insignificant while the declining of the average size of system over time becomes significant.

Number of Project Components

The number of project components is intended to capture the degree of project complexity. The result showing a significant negative impact on EIRR is quite intuitive. The more complex a project becomes, the more likely that it will have lower economic returns. For India, the 5-year averages in Table 3 show projects to have fewer components over time, however, no statistically significant trend is established.

External Funding Agency Staff Input for Supervision

Input of staff from the external funding agency for supervision has a negative impact on the project's performance: the larger the staff input for supervision, the lower the economic returns. A caution on this variable is that it may be introducing a simultaneous problem in the regression equation, i.e., the external funding agency input for supervising a project may be larger because the performance of the project is poor, or the performance of a project may be better because the external funding agency spends more staff time on the project. The data reveal that the former is the case.[15] That is, the data apparently capture the higher supervision inputs required for troubled projects, which are likely to perform poorly.

This variable is of interest given the fact that in India, external funding agency staff supervision is shown to be significantly increasing over time and substantially higher than projects in other countries or regions. Supervision inputs appear to proxy for implementation difficulties, which may be pulling down economic returns. The regression result points to the need to carefully understand the underlying reasons for the high supervision inputs in India. Pitman (2002) identifies the sources of difficulties in implementation to include institutional and political factors. Specifically, he cites that in India, projects suffer from inadequate advanced preparation, incomplete engineering designs, insufficient staffing, land acquisition and resettlement, and procurement.

Annual Rainfall and Conjunctive Use of Surface Water and Groundwater

We take annual rainfall in the area where an irrigation project is located as a proxy measure for water availability. For the global level analysis this variable has a positive impact on economic performance, i.e., the higher the annual rainfall, the better the project performance (Table 7). This result suggests that there is a causal link between the amount of rainfall and project performance. Increased water availability and easier access to water translate to higher yields and higher economic returns.

---

[15] The exclusion of this variable alters a little the results of the regression analysis. This observation suggests that the bias due to simultaneous nature of regression equation, if any, is not large.

The result of our global analysis shows that conjunctive water use improves project performance significantly. Irrigation projects that use surface water and groundwater conjunctively have higher economic returns than those which use single sources, even without considering the private development of groundwater, which is not captured in this analysis. In the sample projects in India, no significant trend is observed for annual rainfall and projects with conjunctive water use.

Real Gross Domestic Product (GDP) Per Capita

An increase in the real national per capita income is shown to significantly reduce the economic performance of irrigation projects. This result says that higher income countries tend to have poorly performing projects. Interestingly, the elasticity of economic performance for this variable is largest among the continuous variables used in the analysis. These findings are important, because they suggest that targeting poorer countries makes better investment sense as projects will be economically more effective.

As economies develop the agriculture sector's contribution to the economy declines. This process usually accompanies increasing income as well as a disparity in productivity between the agriculture sector and the non-agriculture sector, the former being left behind. Such a situation leads to agricultural protectionism policies where farmers in high-income countries get more support and subsidies. Implementation of high-cost and low-performance projects is justified on the grounds of protecting disadvantaged farmers, overshadowing economic merits.

India's increasing real GDP per capita and its declining economic returns from public investments in irrigation over time appear consistent with this result. The explanation above seems still not completely relevant for India considering that she is still not exactly a high-income country. However, if we take into account India's relatively heavily subsidized agriculture sector, which simulates the above mentioned characteristic of high subsidies in high income countries, the result becomes logical.[16]

Farmers' Contribution to Investment Cost

Where farmers contribute to project development, projects perform better than those without farmer contribution. The promotion of farmers' contribution to irrigation projects has been pursued more eagerly since the 1980s as a part of a strategy to adopt more participatory approaches. This policy is believed to lead to a greater sense of ownership among the beneficiaries of irrigation systems constructed/rehabilitated by the project, and results in more sustainable projects while reducing the financial burden of the implementing agencies. Evaluations of this policy have shown that farmer contribution leads to more successful participatory processes and greater successes of irrigation projects (Bruns 1997). The result in this study confirms these earlier findings, and supports a policy that encourages farmers to

---

[16] See, for instance, Raju and Gulati (2005) and Gulati and Narayanan (2003) on subsidies in Indian agriculture and irrigation.

contribute to the project cost, on the grounds that it serves as an incentive to use the investment funds more effectively for the farmers' needs and priorities.

Contrary to expectation, India shows a declining pattern for projects with farmers' contribution to investment cost. This trend may reflect either of two things: 1) that the government was reluctant to fully implement such a policy for fear of burdening farmers beyond their means or 2) there were attempts to implement but farmers succeeded in resisting such policies and, as such, more projects ended up with just the government and an external funding agency covering the investment cost.

New Constructions from Rain-fed Areas

Among the projects by purpose, new constructions from previously rain-fed areas show a significantly negative impact on economic returns relative to pure rehabilitation projects, i.e., former has a lower economic performance than pure rehabilitation projects. This difference in performance can be attributed to spill over effects from the cost side given the large economies of scale and the fact that cost as an important variable in the estimation of economic returns. Also, from the global regression analysis, total irrigated area is found to be a major factor influencing performance. In our sample, pure rehabilitation projects happen to be generally bigger in total irrigated area than new constructions from rain-fed areas. India is not shown to be implementing more projects of the type of new constructions from rain-fed areas, but such projects are proposed under the NRLP. What this analysis shows is that new constructions are not likely to perform better than rehabilitation projects, and that therefore, a more careful evaluation is warranted.

Mode of O&M for Systems

Another important variable that has a significant impact on performance is the mode of O&M for irrigation systems after completion of the project. A clear shift in the mode of O&M in irrigation systems from 'government-managed' to 'government+farmer-managed' and 'farmer-managed system' is observed from the global data. The participation of farmers in irrigation projects and system management, through the establishment of water users' associations (WUAs), has been central to the efforts to improve project performance and sustainability of irrigation systems in the last two decades (Merrey 1997; Vermillion 1995, 1991; Vermillion and Johnson 1995). The regression results show that projects with farmer-managed systems perform better than those that are solely government-managed. Also, projects with O&M shared by the government irrigation agency and farmer-beneficiaries through WUAs perform better than those that are solely government-managed. The poor irrigation management by a government monopoly reflects the lack of accountability and incentive to deliver quality service and water supply. This is exacerbated by the absence of a link between irrigation quality, revenues generated from irrigation service fees and staff incentives (Gulati and Narayanan 2003; Gulati et al. 2005). The existence of well-established and operational WUAs has been associated with better maintenance of systems and more efficient water deliveries, which in turn have led to higher yields and better economic performance of irrigation projects (Raju and Gulati 2005; Gulati et al. 2005; Gulati and Narayanan 2003).

One can see from Table 2, that India's solely government-managed systems are declining while systems jointly managed by the government and farmers are increasing. The Government of India has adopted institutional reforms that shift more responsibilities to farmers by establishing WUAs. In fact, efforts in this direction began as early as the 1970s and were accelerated significantly in the mid-1980s. From the sixth to the ninth '5-year plans', participation of farmers in various aspects of management of the irrigation system has been recognized as important, and endorsed and promoted as a central strategy in irrigation development and management. In the 1999-2000 central government budgets, a one-time management subsidy was given to states to form WUAs. However, many studies have pointed out how the process has been slow in taking off and the difficulties in making WUAs work, which range from institutional to technical and social (Gulati et al. 2005; Raju and Gulati 2005; Barker and Molle 2005; Gulati and Narayanan 2003; Shah et al. 2002; Vermillion 1991, 1995; Vermillion and Johnson 1995). The results in this paper do not claim that these difficulties and problems are non-existent but looking at the projects' economic performance, systems with farmers involved in O&M have done better than those that were solely government-managed. These results reinforce the recommendation of Gulati et al. (2005) that farmers should be treated as clients, shareholders or as co-managers of irrigation systems rather than just beneficiaries. Farmers' organizations will in fact play a more significant role in O&M of systems if treated as co-managers.

A better understanding of the factors that influence the participation of farmers in WUAs and the WUA's viability should help turn around this slow progress. Gulati et al. (2005) identified the factors that can positively influence farmer participation as follows: (a) where a minor system serves mostly one village rather than multiple villages; (b) sites with temples or religious centers;[17] (c) large command areas that are closer to markets; and (d) presence of community organizers or potential leaders.

Irrigated Crops

In terms of the type of crops irrigated, systems irrigating vegetables, tree crops, and fodder are shown to perform better than those irrigating paddy. As a result of irrigation development since the 1960s and the subsequent success of the green revolution since the 1970s, the price of rice has been declining sharply in real terms since the early 1980s. This trend in turn resulted in the historic low-profitability of rice production over the last two decades. In contrast, price prospects are much better for fruits, vegetables and livestock products, the demand for which increases as the economy develops. Better price prospects for fruits, vegetables, and livestock products that use fodder contribute to the higher project performance of these systems when compared to the rice systems. Systems that irrigate high-value crops enjoy higher economic returns because of the higher profitability of the crops irrigated.

---

[17] Sites with religious centers are said to have a greater chance of organizing systems for irrigation with the centers themselves becoming the focal points for local social capital.

Agriculture diversification in India began in the 1980s but gathered momentum in the 1990s (Joshi et al. 2007, 2005). Rising income, changing relative prices between cereals and high-value agriculture, increasing urbanization and infrastructure and more open trade policies are among the factors identified to have driven this change (Joshi et al. 2007).

From our data, the trends in India's irrigated crops (Table 2) show that paddy irrigation is declining while irrigation for other cereals is rising. Despite policy pronouncements encouraging the shift to high-value crops, it appears that the country has still a long way to go to realize significant diversification levels. While not discounting the associated risks and difficulties in irrigating high-value crops, such as vegetables and even tree crops and fodder, our results show that systems irrigating these crops have done significantly better than those irrigating paddy. This is an opportunity that India can seriously consider and take advantage of.

Joshi et al. (2007) have established the determinants of crop diversification. Among the factors identified are: a) infrastructure development as captured by markets and roads; b) technology as captured by irrigated area; c) the relative profitability of horticultural commodities; d) the proportion of smallholders; e) climate as captured by the amount of rainfall; and f) demand-side factors such as urbanization and per capita income. The paper suggests that assured markets and good road networks are key determinants that could stimulate agricultural diversification in favor of high-value crops, as they maximize profits and minimize uncertainty in output prices. Interestingly, the higher the technology adoption for the production of cereal crops as proxied by irrigation, the less was the diversification in favor of high-value commodities. This particular factor points to the potential of diversification in areas where less water is available. Also, another significant finding is that high-value commodities are usually produced by small farmers.

To promote agricultural diversification and meet the demand for high-value commodities, Gulati et al. (2007) recommend improvement of incentives, institutional reforms and increased investment. Specifically, improving incentives basically means 'getting the prices right' by adjusting the high and guaranteed prices for staple grains and reducing subsidies on power, irrigation and fertilizers, and reallocating the funding to basic infrastructure development, excluding irrigation. Reforming institutions include 'getting the markets right' by leveling the playing field, improving land-use and credit access, reinvigorating technology development and dissemination, and promoting improved food-safety and quality. As for the required investment, the authors suggest more investment in roads and markets, electricity supply, information and communication technologies (ICT), and improving the climate for private investment.

Regional Effects

South Asia has the lowest EIRR among all regions with the exception of South East Asia. This means that, once the factors with significant impacts on performance are accounted for, irrigation projects in South Asia, generally, have lower economic returns than those in SSA, MENA, LAC and East Asia. This is another cause for concern, especially if we consider that India's EIRR is significantly decreasing over time. There is however, a potentially significant opportunity for addressing and reversing these trends of the relatively low and declining EIRR.

Lessons from the Global Experience and the Way Forward for India's Irrigation Sector

Summary and Conclusions

This paper offers certain insights on irrigation projects in India based on a consistent set of data for 314 irrigation projects implemented in developing countries worldwide in the last four decades. The database includes 37 projects for India, which accounts for 24 % of the official irrigated area in 2001, a significant sub-set. We examined trends in the economic performance of irrigation investments in India, determined the factors that influenced performance of the global sample and drew lessons for future irrigation projects in India.

Our analysis indicates that the performance of irrigation investments in India by the government and key external funding agencies has been declining with time, whereas at a global level they have, in fact, been on an upward trend. No significant trend is established for the unit cost of the sample irrigation projects in India, implying that cost may have little to do with the decline in project performance or that factors other than costs must have more dominating effects. Having said that however, another recent study that used annualized data found that state-level and India-wide unit costs are increasing.

The share of the Indian Government in total investment cost has declined relative to that of the external funding agencies. Projects with farmers contributing to their development too are declining. The decline in government counterpart funding in irrigation projects is consistent with the decline in the budget allocation of the central government for irrigation and the irrigation expenditures of the states, especially since the 1980s (Gulati and Narayanan 2003). The declining pattern for projects with farmers' contribution to investment cost may reflect either of two things: 1) that the government was reluctant to fully implement such a policy for fear of burdening the farmers beyond their means or 2) there were attempts to implement but farmers succeeded in resisting such policies and more projects ended up with just the government and an external funding agency covering the investment cost.

This paper finds that as far as irrigation project size (in terms of total irrigated area) is concerned, there are underlying significant economies of scale. To assert that large-scale projects are bound to fail cannot be supported by the data, because small projects are more likely to perform poorly in comparison with large irrigation projects. Furthermore, rehabilitation projects perform better than new irrigation projects developed in previously rain-fed areas.

However, our results also suggest that at the system or scheme level, how projects are managed appears to be more important than scale. The increasing project size or total irrigated area trend in India appears consistent with the regression result. However, if the trend is adjusted by taking out the Haryana Water Resources Consolidation (HWRC) project from the sample as it has an extremely large total rehabilitated irrigation area, the increasing project size trend becomes insignificant while the trend in average system size decreases significantly. The declining pattern for average size of system in India (without HWRC in the India sample) is consistent with the result on average size of system of the global analysis.

Supervision by the staff of external funding agencies was shown to be significantly increasing over time, and substantially higher in India's projects than those in other countries or regions. This observation could reflect serious implementation constraints that however, have to be properly understood and addressed if projects are to succeed. Among the cited sources of difficulties in implementation are; inadequate advanced preparation; incomplete engineering designs; insufficient staffing; land acquisition and resettlement; and procurement. The declining cost overruns, while not directly affecting economic performance, is a good indication that efforts toward improving implementation are succeeding.

The current trend of the systems in India are the same as those in global systems, i.e., wholly government-managed systems are declining and those jointly managed by government and farmers are increasing. While there are no systems that are solely managed by farmers in the Indian sample, systems that do not involve any government agency are reported in the global sample to perform the best. The Government of India has embraced this policy of shifting more responsibilities to farmers by establishing WUAs. However, several reports have pointed out that while the process of implementing such a policy has been very slow, it has also been increasingly difficult to ensure the viability of the WUAs themselves.

The trends in India's irrigated crops show that paddy irrigation is declining while irrigation for other cereals is rising. Despite policy pronouncements encouraging the shift to high-value crops, it appears that the country is yet to realize such crop diversification. While not discounting the associated risks and difficulties in irrigating high-value crops, systems irrigating these crops have done significantly better than those irrigating paddy. This is an opportunity that India can seriously consider and take advantage of.

In terms of type of project by purpose, the trends in India appear to be consistent with the global regression results with investments declining in new construction projects from rain-fed areas and increasing in pure rehabilitation projects, the latter of which have relatively higher economic returns. The trends in the type of system show that both tank and groundwater-lift systems are on the rise while drainage/flood control projects are decreasing significantly. While not having direct impacts on economic returns, investments in these types of system may have adverse environmental impacts, which would in turn impact on water quantities and eventually on irrigation performance.

Recommendations

What are the lessons from the global sample for India? The analysis shows that public investments in large irrigation projects do perform positively from an economic perspective. Furthermore, larger projects tend to do better than the smaller scale investments. While investments in such projects have diminished recently, further investments of this type are proposed under the NRLP and are part of the overall justification of the planned inter-basin transfers. While such investments have been shown to have a positive economic performance and could be appropriate components of specific transfers, this is only true for those projects that are primarily connected with the rehabilitation of existing systems. The same does not hold true where projects have been developed on previously rain-fed lands, and such new constructions have generally performed poorly. Furthermore, given that this analysis does not incorporate the role of private sector investments in groundwater development, this factor needs to be further examined to determine whether the economic performance was greater where investments were made to support groundwater irrigation, such as groundwater recharge.

The policy of giving farmers increased roles in the operation and management of irrigation systems have had mixed results. Most of the available evidence are at the micro level or are scheme-specific and, as such, cannot give a clear recommendation on whether this policy agenda should be continued or not. More studies have reported the problems of such policies and why programs such as irrigation management transfers cannot or do not work. The result in this paper is in line with more recent evidence, which shows the more promising and positive impacts of greater farmer participation in irrigation O&M, in terms of enhancing project performance. The direction of the government and donors in encouraging more farmer participation, with the former providing supporting roles, should be continued. However, while the results provide support for such a policy, the inherent difficulties and challenges in making participatory initiatives work should not be underestimated. Building capacities and stronger farmer groups require considerable time and resources, which the government and donors should invest in, in order for projects to be sustainable.

The idea of shifting from largely food cereal production to higher value crops has been initially met with less interest by decision-makers, yet has been occurring on the ground. Farmers are believed to be inflexible in shifting from one crop to another, especially since such diversification entails higher risks, which farmers cannot afford and requires greater technical skills that most farmers are said not to have. However, this paper provides empirical support to the policy of crop diversification in irrigation projects and indicates that, it is in the direction of achieving better project economic performance. Yet, this argument is not implying that the government can encourage diversification without taking into account various factors. Complementary public investments in basic infrastructure such as roads and access to information, input and output markets, and access to financial capital, should reduce the attendant risks for farmers and serve as incentives to take advantage of the opportunity and benefit from investments in irrigating higher value crops.

While this paper offers certain key investment areas, which can be pursued by the Government of India and the international development community, it has not addressed the role of the private sector in agricultural water development and management. This knowledge should complement the recommendations espoused in this paper. From the above, it is clear therefore, that there are areas that would need further and careful study, particularly with regard to ensuring the economic performance of major investments in irrigation in the context of inter-basin transfers, and increasing water scarcity.

References

Adams, W. M. 1990. How beautiful is small? Scale, control and success in Kenyan irrigation. *World Development* 18 (10): 1309-1323.

ADB-PEO (Asian Development Bank-Post-Evaluation Office). 1995. Sector synthesis of post evaluation findings in the irrigation and rural development sector (May 1995). Manila, the Philippines: ADB.

Amarasinghe, U. A.; Sharma, B. R.; Aloysius, N.; Scott, C.; Smakhtin, V.; de Fraiture, C.; Sinha, A. K.; Shukla, A. K. 2005. *Spatial variation in water supply and demand across river basins of India.* IWMI Research Report 83. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Barker, R.; Molle, F. 2005. Perspectives on Asian irrigation. In *Asian irrigation in transition - Responding to challenges*. (eds) G.P. Shivakoti, D.L. Vermillion, W. Lam, E. Ostrom, U. Pradhan, R. Yoder. New Delhi, India: Sage Publications. p 45-78, Box, G. E. P.; Cox, D. R. 1964. An analysis of transformations. *Journal of the Royal Statistical Society. Series B (Methodological)* 26: 211—243.

Brown, E.; Nooter, R. 1992. Successful Small-Scale Irrigation in the Sahel. World Bank Technical Paper No. 171. Washington, D.C., USA: World Bank.

Bruns, B. 1997. *Reflections on turning over irrigation to farmers: Collected papers 1989-1994.* Internet [accessed in June 2005]. http://home.vol.com/~bryanbruns /0content.html.

Fan, S.; Hazell, P.; Thorat, S. 1999. *Linkages between government spending, growth, and poverty in rural India.* IFPRI Research Report 110. Washington, D.C., USA: IFPRI.

FAO. 2004. AQUASTAT.http://www.fao.org/waicent/faoinfo/agricult/agl/aglw/aquastat/ *(*accessed in 2004).

Greene, W. H. 2003. *Econometric analysis, 5th edition.* New Jersey, USA: Prentice Hall.

Gulati, A.; Joshi, P.K.; Cummings Jr., R. 2007. Chapter 20: The way forward – Towards accelerated agricultural diversification and greater participation of smallholders. In *Agricultural diversification and smallholders in South Asia*. (eds) P.K. Joshi, A. Gulati and R. Cummings Jr. New Delhi, India: Academic Foundation. pp 603-621.

GOI (Government of India). 2004. *Agricultural statistics at a glance 2004.* New Delhi, India: Ministry of Agriculture.

Gulati, A.; Meinzen-Dick, R.; Raju, K.V. 2005. *Institutional reforms in Indian irrigation*. New Delhi, India: Sage Publications.

Gulati, A.; Narayanan, S. 2003. *The subsidy syndrome in Indian agriculture*. New Delhi, India: Oxford University Press.

Inocencio, A.; Kikuchi, M.; Tonosaki, M.; Mayurama, A.; Merrey, D.; Sally, H.; De Jong, I. 2007. *Costs and performance of irrigation projects: A comparison of sub-Saharan Africa and other developing regions*. IWMI Research Report 109. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Jones, W. I. 1995. The World Bank and Irrigation. Washington, D.C., USA: World Bank.

Joshi, P.K.; Gulati, A.; Birthal, P.S. 2007. Chapter 7: Agricultural diversification in India – Status, nature and pattern. In *Agricultural diversification and smallholders in South Asia*. (eds) P.K. Joshi, A. Gulati and R. Cummings Jr. New Delhi, India: Academic Foundation. pp 219-242

Joshi, P.K.; Gulati, A.; Birthal, P.S.; Tewari, L. 2005. Chapter 12: Agriculture diversification in South Asia – Patterns, determinants and policy implications. In *Economic reforms and food security*. (eds) S. C. Babu and A. Gulati. New York, USA: Haworth Press, Inc. pp. 259-287

Kikuchi, M.; Maruyama, A.; Hayami, Y. 2003. Phases of irrigation development in Asian tropics: A case study of the Philippines and Sri Lanka. *Journal of Development Studies* 39 (5): 109-138.

Meinzen-Dick, R.; Rosegrant, M. 2005. Chapter 10: Emerging water issues in South Asia. In *Economic reforms and food security*. (eds) S. C. Babu and A. Gulati. New York, USA: Haworth Press, Inc. pp. 213-229.

Merrey, D. 1997. Expanding the frontiers of irrigation management research: Results of research and development at the International Irrigation Management Institute, 1984-1995. Colombo, Sri Lanka: International Water Management Institute (IWMI) 228pp

Mundle, S.; Mukhopadhya, H.; Roy, S.S. 2003. ADB India Economic Bulletin. Vol. 1 No. 2. (June). New Delhi, India: ADB India Resident Mission.

Peacock, T.; Ward, C.; Gambarelli, G. 2007. Investment in agricultural water for poverty reduction and economic growth in sub-Saharan Africa. Synthesis Report. A collaborative programme of ADB, FAO, IFAD, IWMI and World Bank.

Peter, J. Raymond. 2003. Capacity building for PIM – The case of Andhra Pradesh. Paper presented at the FAO/ICID International Workshop on Capacity Building for Irrigation and Drainage, Montpellier, France.

Pitman, G.T.K. 2002. India: World Bank Assistance for Water Resources Management: A Country Assistance Evaluation. Operations Evaluation Department Working Papers. Washington, D.C, USA: World Bank.

Raju, K.V.; Gulati, A. 2005. Chapter 11: Pricing, subsidies, and institutional reforms in Indian irrigation. In *Economic reforms and food security*. (eds) S. C. Babu and A. Gulati. New York, USA: Haworth Press, Inc. pp. 231-255.

Rosegrant, M. W.; Perez, N. 1995. Water Resources Development in Africa: A Review and Synthesis of Issues, Potentials, and Strategies for the Future. Washington, D.C., USA: International Food Policy Research Institute (September).

Rosegrant, M. W.; Svendsen, M. 1993. Asian food production in the 1990s: Irrigation investment and management policy. *Food Policy* 18 (1):13-32.

Shah, T.; van Koppen, B.; Merrey, D.; de Lange, M.; Samad, M. 2002. *Institutional alternatives in African smallholder irrigation: Lessons from international experience with irrigation management transfer.* IWMI Research Report 60. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Vermillion, D. 1991. *The turnover and self-management of irrigation institutions in developing countries*. Discussion Paper. Colombo: International Irrigation Management Institute (IIMI)

Vermillion, D. 1995. Irrigation management transfer: Towards an integrated management revolution. In *Irrigation management transfer: Selected papers from the International Conference on Irrigation Management Transfer*. Wuhan, China, September 20-24, 1994, (eds) S.H. Johnson, D.L. Vermillion, and J.A. Sagardoy. Rome, Italy: IIMI and FAO.

Vermillion, D. Johnson, S. 1995. Globalization of irrigation management transfer: A summary of ideas and experiences from the Wuhan Conference. In *Irrigation management transfer: Selected papers from the International Conference on Irrigation Management Transfer*, Wuhan, China, September 20-24, 1994, ed. S.H. Johnson, D.L. Vermillion, and J.A. Sagardoy. Rome, Italy: IIMI and FAO.

Vyas, V.S. 2003. Indian agriculture – The unresolved issues. Special feature In India Economic Bulletin, Vol. 1 No. 2. (June). New Delhi, India: ADB India Resident Mission.

World Bank. 2004. Water resources sector strategy: strategic directions for World Bank engagement. Washington D.C., USA: World Bank.

World Development Indicators (WDI) Online. Internet download. http://devdata.worldbank.org/dataonline/ (accessed in September 2004).

Annex Table 1. Total area irrigation by projects in sample, 1965-1999[a].

	Total number of irrigation projects	Total area irrigated ('000 ha)
Asia		
All projects	177	42,960
New construction projects	63	5,016
Rehabilitation projects	114	37,944
South Asia		
All projects	91	29,065
New construction projects	32	3,467
Rehabiliation projects	59	25,598
India		
All projects	37	13,006
New construction projects	20	2,527
Rehabilitation projects	17	10,479
All Regions		
All projects	314	53,684
New construction projects	126	7,105
Rehabilitation projects	188	46,578

Sources of basic data: Various project documents of the World Bank, African Development Bank and International Fund for Agricultural Development, various years

Notes: [a] The years indicate 'year of project start' rather than year of project completion

Annex Table 2. List of sample projects, India (n=37).

Project title	Year project started	Total project area under new construction (ha)	Total project area under rehabilitation (ha)	Total irrigation cost in 2000 prices (million US$)
Kadana Irrigation Project	1971	80,540		421.1
Pochampad Irrigation Project	1972	75,000		530.5
Chambal Command Area Development Project (Rajasthan)	1975		197,000	136.7
Chambal Command Area Development Project (Madhya Pradesh)	1976		222,635	59.8
Rajasthan Canal Command Area Development Project	1974	136,000	108,000	243.7
Goodavari Barrage Project	1975		400,000	112.4
West Bengal Agricultural Development Project	1977	86,100		77.7
Andhra Pradesh Irrigation and CAD Composite Project	1978		560,764	240.0
Periyar Vaigai Irrigation Project	1978	17,100	63,200	62.2
First Maharashtra Composite Irrigation Project	1979	87,000	30,000	246.4
Karnataka Irrigation Project	1980	97,330	69,900	553.4
Orissa Irrigation	1979	60,000	57,000	136.9
Gujarat Medium Irrigation Project	1979	134,400	33,600	406.2
Punjab Irrigation Project	1980		1,200,000	371.7
Haryana Irrigation Project	1979		1,270,000	237.5
Uttar Pradesh Public Tubewells Project	1981	60,225		44.4
Gujarat Irrigation II Project	1981	41,766	93,173	271.6
Maharashtra Irrigation II Project	1980	66,800		582.3
Karnataka Tanks Irrigation Project	1983	16,800		69.8
Mahanadi Barrages Project	1982		167,000	143.1
Madhya Pradesh Medium Irrigation Project	1982	127,617		222.7
Kallada Irrigation and Tree Crop Development Project	1983	12,600		149.7
Madhya Pradesh Major Irrigation Project	1982	360,000	269,000	495.3
Haryana Irrigation II Project	1983		1,270,000	242.6
Second Uttar Pradesh Public Tubewells Project	1984	385,000		241.2
Chambal (Madhya Pradesh) Irrigation II Project	1983		221,000	49.4
Maharashtra Water Utilization Project	1984		115,203	61.8
Upper Ganga Irrigation Modernization Project	1984		701,000	275.1
Periyar Vaigai Irrigation II Project	1985	7,500	73,600	69.5
Gujarat Medium Irrigation II Project	1985	279,696	60,804	471.3
West Bengal Minor Irrigation Project	1987	59,500		93.0
National Water Management Project	1988		640,000	164.3
Bihar Public Tubewell Project	1988		240,320	110.4
Maharashtra Composite Irrigation III Project	1987	227,800		344.4
Upper Krishna Irrigation Project (Phase II)	1990	93,513		694.0
Haryana Water Resources Consolidation Project	1995		2,300,000	442.8
Punjab Irrigation and Drainage Project	1990	15,000	115,719	221.5
Total		2,527,287	10,478,918	9,296.6

Annex Table 3. Definition of variables used in the regression analysis of the global irrigation project sample.

Variables	Definition
Total project cost	Total irrigation-related investment which includes both physical irrigation infrastructure and software components (e.g., agriculture supports and institution building); excludes non-irrigation costs (e.g., power generation and non-irrigation components in sector-wide projects), in US$ million at 2000 prices (Deflator; IMF world export price index)
Unit cost	Total project cost divided by project size (US$ 000/ha)
EIRR	Economic internal rate of return at project completion or audit (%)
Project size	Total project area = total irrigated area benefited by a project (000 ha)
Average size of systems	Average command area of irrigation systems involved in a project (project size/number of irrigation schemes involved in the project) (000 ha)
Year project started	The year the implementation of the project started
Bank input for supervision	Staff weeks spent for project monitoring and supervision
Time overrun	The number of years between the project completion and the planned completion year in appraisal
Cost overrun	The ratio of the actual investment to the palnned one in appraisal (%)
Sizing error	The ratio of the difference between planned and actual irrigated area benefited by the project to the planned irrigated area (%)
No. of project components	Number of project components listed in appraisal report, taken as a proxy to measure the complexity of the project
Share of government fund	Share of government fund in total investment (%)
Share of soft components	Share of such software cost components as engineering management, technical assistance, agricultural support and institution building in total investment (%)
Farmers' contribution[a]	Whether or not farmers contribute to the project investment
Conjunctive use of water[a]	Whether or not surface water groundwater is used conjunctively
Annual rainfall	Annual rainfall in the project area (mm), obtained from SAR, or from the FAO Aquastat
GDP per capita	GDP per capita during the project period (US$ in 2000 prices)
PPP	Purchasing power parity converstion factor to official exchange rate ratio during the project period

Note: [a] A binary variable with the value of '1' if the characteristic is present and '0' if absent

Annex Table 4. Classifications of the global sample of irrigation projects.

Classification[a]	Description
Type of project	
Irrigation	Project for irrigation alone
Irrigation and power	Project for irrigation and electrical power generation
Multi-sector	Multi-sector projects including irrigation components
Purpose of project	
New construction with land opening	New irrigation construction projects converting unused land into irrigated fields
New construction from rain-fed area	New irrigation construction projects converting rain-fed fields into irrigated ones
New construction + Rehabilitation	Newly constructed area > rehabilitated area
Rehabilitation + New construction	Rehabilitated area > newly constructed area
Rehabilitation	Irrigation rehabilitation / modernization projects without newly created area
Type of irrigation system	
River-diversion	Without major storage capacity
River-dam-reservoir	With a major storage capacity
Tank	With tank as the major source of irrigation water
River-lift	Pump system with water from river, pond or lake
Groundwater-lift	Pump system with groundwater
Drainage / flood control	Systems where water is used by draining excess water out of the system area
Mode of O&M after project	
Government agency alone	O&M by government agency alone
Government + farmer	O&M with government agency and farmers' organizations (water users' groups)
Farmer-managed system	Systems managed by farmers with minimal intervention by government agencies
Major crops irrigated	
Paddy	
Cereals	Wheat, maize and other cereals
Sugar/Cotton	
Tree crops	
Vegetables	
Fodder	
Region	
SSA	sub-Saharan Africa including 19 countries
MENA	Middle East and North Africa including 8 countries
SA	South Asia including 5 countries
SEA	South-East Asia including 7 countries
EA	East Asia including 2 countries
LAC	Latin America and Caribbean including 9 countries
Donor[b]	
WB	World Bank
AfDB	African Development Bank
IFAD	International Fund for Agricultural Development

Notes: [a] Underlined items are used as the base variable in each variable group when these binary variables are used as dummy variables in regression analysis

[b] Major donor agency; co-financing project is listed under the major donor

Benefits of Irrigation Water Transfers in the National River Linking Project: A Case Study of Godavari (Polavaram)-Krishna Link in Andhra Pradesh

Anik Bhaduri, Upali A. Amarasinghe and Tushaar Shah
International Water Management Institute, New Delhi, India

Introduction

The Comprehensive Assessment of Water Management Report of the International Water Management Institute (IWMI) states that presently one third of the world population face some form of water scarcity (Rijsberman 2006). Several hydrological projections have also indicated that in the future, water availability may plummet to a point where it intensifies water-scarcity, and may even become a global threat to human development (Barbier 2004). Such a widening gap between the demand and supply of freshwater has prompted the Consultative Group on International Agricultural Research to initiate a Challenge Program on Water and Food (CPWF) and address the concerns about global food and water scarcity.

Many articles (Howe et al. 1986: Saleth 2001) have identified two fundamental ways to meet water-scarcity. First, water-scarcity can be mitigated by managing the demand for water. Water demand management (WDM) offers the potential to increase water availability by coupling proper water allocation with efficient use. However, mitigating water scarcity only by managing demand has its limitations. Its implementation has been fraught with numerous difficulties and constraints, most of which relate to the lack of enabling environment and institutional capacity for the adoption and implementation of Integrated Water Resources Management (Ncube et al. 2006).

Second, water scarcity can be met by augmenting the supply of water. Inter-basin water transfer often is viewed as an instrument to mitigate water scarcity through the diversion of water from a water-surplus part of a given river basin system to one or more water-deficit areas in another river basin. (Bhaduri 2005). The main objective behind the implementation of such projects is to continuously meet the existing and future water demand in the face of decreasing relative water availability. Creating new sources to augment water supply requires large investments and effective institutions for allocating water.

As part of the CPWF program, International Water Management Institute (IWMI) has undertaken a study to examine the viability of inter-basin water transfers in meeting water scarcity in water-deficient zones. The paper particularly explores the benefits of surface water augmentation in the agricultural sector.

The primary focus of the paper is India's National River Linking Project (NRLP). The choice of the case study is well justified in the sense that India is no exception to the general global trend of rising demand for freshwater. There is little doubt to the popular belief that access to freshwater availability in India has depleted over the years and, is likely to worsen in the coming years. The per capita water availability of 5,400 cubic meters per person in 1950 has decreased to 1,900 cubic meters per person in 2000 (Amarasinghe et al. 2005). Added to this, there has been a large regional spatial variation in different river basins in terms of water and food availability. As a consequence of spatial variations in different river basins, the Government of India has proposed several inter-basin transfer schemes. The project has the specific aim of diverting 'surplus' water from the Himalayan rivers in the north and east to water deficit areas in the peninsular and western India for development uses, e.g., irrigation, urban water supply, industrial use and hydro-electricity.

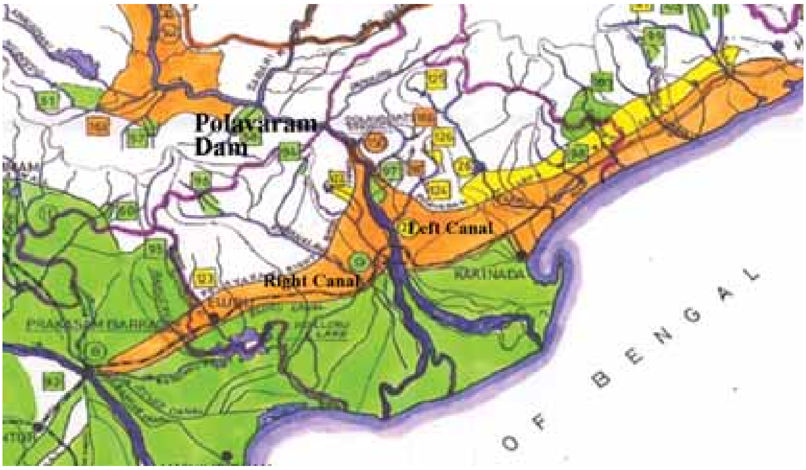
The National Water Development Agency (NWDA) of India has identified 30 Himalayan and peninsular rivers for such inter-basin water transfers (NWDA 1999). The Himalayan component consists of 14 links that involves transfers from the Ganges-Brahmaputra-Meghna basins, while in the peninsular component the water transfers would take place among 16 rivers that include the Mahanadi, Godavari, Krishna, Pennar, and Cauvery river basins. Among the peninsular component, the Godavari River has been considered as the sizeable surplus, and it is proposed that this river will transfer its surplus water to the Krishna, Pennar and Cauvery river basins. The paper illustrates the Godavari Link, and explores the potential economic benefits of the link for the agricultural sector. The scope of the study is confined to the agricultural sector as much of the water is used for agricultural purposes.

The Polavaram Project

The Godavari is the second largest river basin in India with about 320,000 km^2 of catchment area, and has been considered as the surplus basin for transferring water to the Krishna River basin. The water diversion is planned to take place entirely within the State of Andhra Pradesh using a dam to be constructed at Polavaram; and then through a 174 km long canal (right main canal) running westward to connect the Krishna River. It has been envisaged by the government authorities that the water diversion will provide irrigation to around 0.14 million ha of cultivated land, besides the transfer of 80 tmc of Godavari waters to the Krishna River (NWDA 1999).

Apart from establishing the Godavari Krishna Link, the Government of Andhra Pradesh has also designed the Polavaram Water Diversion Project so that it could be developed into a multi- purpose project. The plans of the project intend to use the diverted water from the Godavari River to provide irrigation benefits to a cultivated command area of 0.175 million hectares in the upland areas of the eastern side of the command area, in addition to supplying water to the city of Visakhapatnam for domestic and industrial purposes. The water transfer will take place through a 208 km long canal running eastwards towards the city of Visakhapatnam (see Figure 1).

Figure 1. Proposed command area map of the Polavaram Dam.



Why Does Andhra Pradesh Need a Polavaram Project?

A perennial shortage of freshwater resources for agriculture, industry and domestic purposes has prompted the Government of Andhra Pradesh to explore in its own way suitable methods to harness the available surface waters. Certain recent observations of irrigation data from Andhra Pradesh suggest that in the past decade, irrigation through surface water sources has largely been overtaken by groundwater irrigation. Subsidized electricity charges and the timely availability of water have encouraged farmers to buy water pumps and exploit the groundwater resource extensively. The consequence is reflected in the falling water tables. The current situation turns out to be double whammy for the state government, in that the government has to continue to pay the subsidies, while depth to groundwater continues to increase. (Narayanmoorthy et al. 2005).

The Government of Andhra Pradesh has spent a considerable amount of money for irrigation and other irrigation reforms. Since the last decade the spending on irrigation is between Rs. 1,500-Rs. 2,000 crores per year. The government's efforts notwithstanding, there has been little improvement in surface irrigation by the government source. Given the urgent need to meet the irrigational water demand, the government has planned to construct few dams and several lift irrigation schemes. The Polavaram Project, embarked upon by the Government of Andhra Pradesh is one such attempt. Presently, much of the water of the Godavari River flows into the Indian Ocean; in that government agencies estimate that around 644 tmcft (18 billion m^3) of water is currently not being utilized from the Godavari, and flows into the sea. Hence, the Government of Andhra Pradesh wants to capture a part of this unused water by constructing a dam at Polavaram.

Objective of the Paper

The research paper contributes in assessing the benefits of irrigation from the proposed Polavaram Dam. Many argue that a major proportion of the economic benefits of the dam could be realized from agriculture, and this is evident from the government's proposal, which indicates that nearly 64 % of the water from the River Godavari will be diverted for irrigation purposes only. The research paper attempts to address the question – how additional surface irrigation facility would help farmers to increase agricultural productivity.

The contribution of the research paper is not confined to direct irrigation benefits only. The paper also raises other hydrological concerns about the potential role of surface water irrigation in cases, where groundwater has been the dominant form of irrigation. The issue is very relevant and much talked about, as groundwater irrigation contributes 67 % of the net irrigated area of the country. Also governmental data sources reveal that in 1997 more than 50 % of cultivable area was irrigated from groundwater sources in the proposed command area of the Polavaram Dam (NWDA 1999). Our research studies indicate that presently groundwater depth is rising in many regions of the command area, and this imposes a severe constraint for the farmers on their crop choice, yield, cost of inputs and agricultural income. The issue is relevant in assessing the benefits of surface water irrigation and particularly considering that surface irrigation could facilitate groundwater recharge, reduce the stress on groundwater resources, and thereby help farmers in increasing the net value of groundwater irrigated land.

Past studies, related to the cost benefit analysis of surface irrigation projects, reveal a trend which suggests that the farmers grow mostly water-intensive crops, for instance, paddy, with the introduction of surface water irrigation. Thus, another issue of importance is whether the farmers who are growing high-value crops using costly groundwater would shift to low-value water-intensive crops such as paddy with surface irrigation. Several studies indicate that increases in productivity through canal irrigation are greater with multi-cropping and the cultivation of more profitable water-intensive cash crops such as sugarcane (Singh 2000). We researched whether surface irrigation would set a broader choice option for farmers in terms of crop diversification.

Livestock is an important source of income for the livelihood of farmers. The study also attempts to assess the livestock benefits that may be generated from the water diversion at Polavaram.

We have relied on the farm level primary survey data to assess the irrigation and livestock benefits of the water transfer, and to answer such questions as discussed above. A sample of 1,000 farmers was selected in the proposed command area, adjacent command area and in the rain-fed areas to evaluate the irrigation benefits.

The structure of the paper is organized as follows - in the next section we briefly explain the methodology in computing the ex ante benefits from the water diversion at Polavaram, after which in the following section, we describe the sampling plan and technique, and in the final section we explore the characteristics of the region.

Methodology and Data

Any assessment of the economic value of surface water generally begins with decisions that define the conceptual and empirical domain of the valuation (EPA 1995). Given an ex ante standing of the Polavaram Project, we define a reference condition for valuation as the existing agricultural and irrigation condition of the proposed irrigation command area, and the expected condition as that of a nearby surface irrigation command area. We, then, define the change in the net value per hectare of land as the differences between the reference condition and expected condition.

Using economic benefit analysis, we identify the changes of, for instance, the cropping pattern, yield, and fertilizer usage, which could be affected by the introduction of surface water in the proposed command area.

Impacts or changes through the introduction of surface water can be measured by estimating the change in the demand and supply functions of the goods and services, resulting from the diversion of surface water, and then measuring the welfare change or change in willingness-to-pay. There are a number of market-based approaches that may be useful in estimating the economic value of changes in the availability of irrigated water. Here, we are adopting a market-based approach in a partial equilibrium framework, to estimate the value of production change in agricultural crops. As the market price of agricultural crops is often distorted by subsidies and the minimum support price, in the given context we will not be considering the change in consumer welfare (consumer surplus).[1]

Calculation of benefits of surface irrigation requires information about area, yield and cropping pattern both before and after the project. There is a dearth of secondary data on the present agricultural and irrigational scenario of the proposed command area. The sample survey has provided us a lot of information to fulfil the requirement to estimate the benefit of irrigation. The information regarding the Polavaram Project, proposed cropping pattern and potential net irrigated area are taken from the Andhra Pradesh Environmental Impact Assessment Report.

Sampling Plan

A stratified random sampling scheme is used for assessing the direct and indirect economic benefits of irrigation water transfers, as a stratified sample can provide greater precision than a simple random sample of the same size, and thus requires a smaller sample to estimate the true characteristics of the population.

---

[1] For such reasons, there is no need to consider the demand side. We can assume that the price of goods is fixed or follows a time trend.

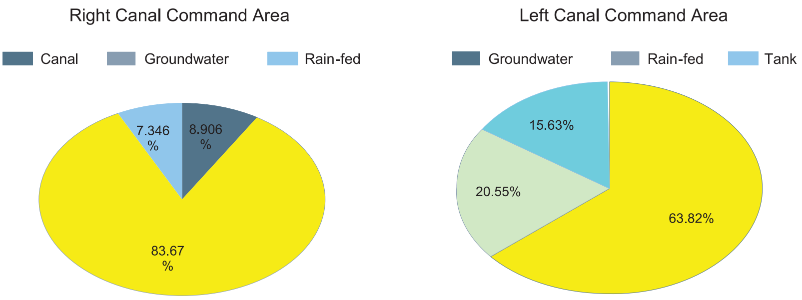
In the stratified random sampling scheme, we first identify the 'mandals' in the command area, which could directly benefit from surface irrigation water transfers. Next, we stratify the mandals/villages according to their distance (head, middle and tail) along the canal. Three mandals/villages are selected from each stratum. The water diverted along the canal may supplement areas already irrigated with surface water or groundwater, or may supply new irrigation water to rain-fed areas. Thus we select the three mandal/s villages from each stratum with one each from the surface irrigation, groundwater irrigation and rain-fed agriculture dominated districts.

We have surveyed around 37 mandals and 50 villages. From each selected village, a sample of 20 farmers is selected. Out of 1,000 farmers surveyed, 521 farmers are located in the right command area and the remaining 479 are located in the left command area.

Present Irrigation Conditions of the Proposed Polavaram Command Area

Assessment of the economic benefits of irrigation requires information about the present irrigation area in the command area. The feasibility report of the project prepared by the National Water Development Authority suggests that 70 % of the cultivable command area en route the right bank was already irrigated a decade back. However, our sample survey data indicates that presently only 9 % of the cultivable area in that area remains unirrigated. On the other hand, in the left canal command area, which forms the other part of the Polavaram Project around 66 % of the farm land, is irrigated. In both components of the command area, however, groundwater is the predominant form of irrigation, and accounts for 85 % and 63.82 % of the net cultivated area in the right bank and left canal command areas, respectively (see Figure 2). This also confirms the national trend of groundwater irrigation growth in India. Today, much of the cultivable area in India is irrigated from groundwater resources. In the absence of new large-scale surface irrigation schemes, and the availability of low-cost electric and diesel pumps coupled with little or no electricity charges, groundwater has been a major driver in the expansion of irrigated area.

Figure 2. Irrigated area source-wise in the canal command area.



Source: Based on authors' estimates

Based on such observations, the premise of our research lies in exploring how the Polavaram command area could benefit from surface irrigation in the case where much of the cultivable area is already irrigated from the groundwater irrigation source.

We hypothesize that the additional source of surface water irrigation can be beneficial but in a limited way, if the farmers in the command area are already using groundwater. After the construction of the Polavaram Dam, surface water can benefit the farmers in the following three ways:

1. After the construction of the Polavaram Dam, farmers who are presently utilizing groundwater may use surface water instead. Lesser dependency on groundwater may help to reduce the agricultural cost.

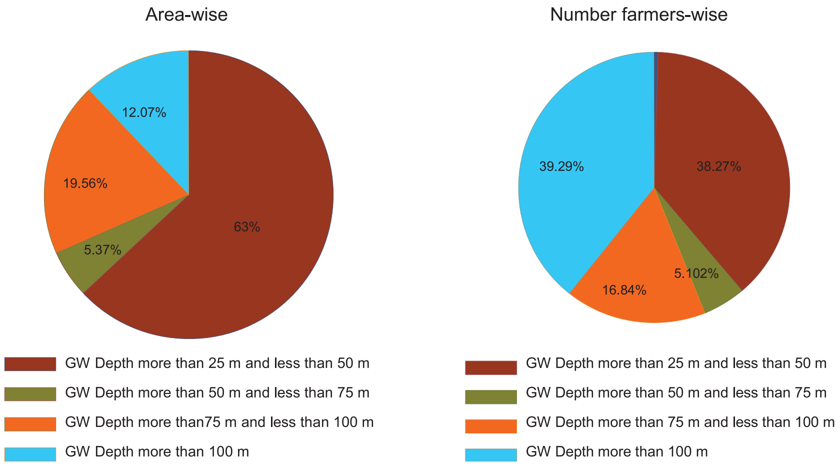
2. Farmers may adopt conjunctive use of groundwater and surface water, which can increase the productivity further.

3. Another potential benefit of a large dam is that seepage from its canals recharges the aquifers, which provide groundwater (Dhawan 1993).

To derive the benefits from surface irrigation, it is imperative to consider the sustainability of groundwater usage. Hence, it is essential to understand a farmer’s agricultural behaviour to changes in groundwater conditions.

In the region, groundwater irrigation has been reported to be beneficial in terms of higher productivity and cropping intensity. However, the growing concern is about groundwater overexploitation and falling groundwater tables in the proposed command area. In about 40 % of the samples, the depth of tubewells is more than 50 meters, and in 12 % of the sample it is deeper than 100 meters (see Figure 3). The groundwater situation is worse, particularly in the right bank command area where in 25 % of the samples, the depth of the tubewells is above 100 meters.

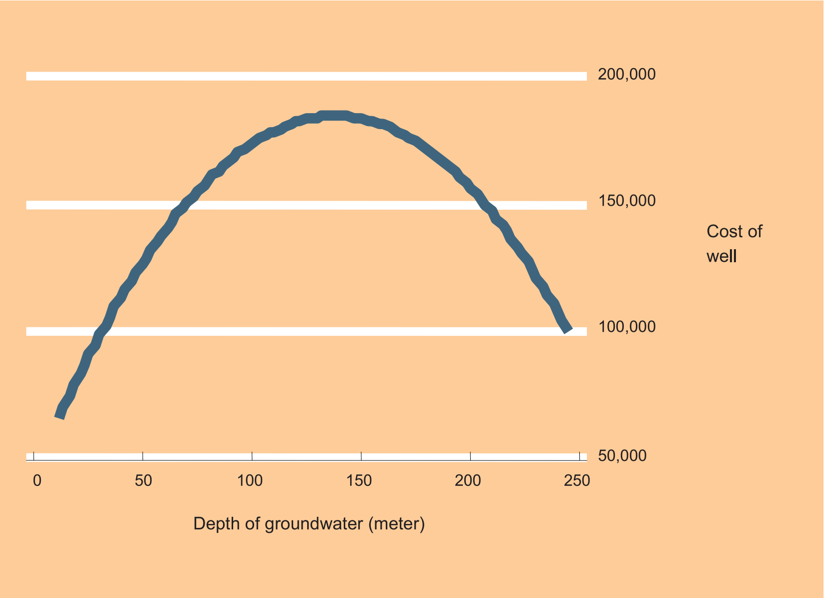
Figure 3. Groundwater depth in the command area: Area and number farmer-wise.



Our analysis suggests that as the depth of groundwater tables increases, farmers invest more in higher capacity pumps, and this is reflected in a concave fitted relationship between the depth of groundwater and cost of tubewells as shown in Figure. 4. Farmers install maximum worth of pumps when the depth of the tubewell is 110 meters. After that the farmers find it economically unfeasible to invest more money in higher capacity pumps for groundwater exploitation, as the marginal cost of groundwater extraction would exceed the marginal benefit.

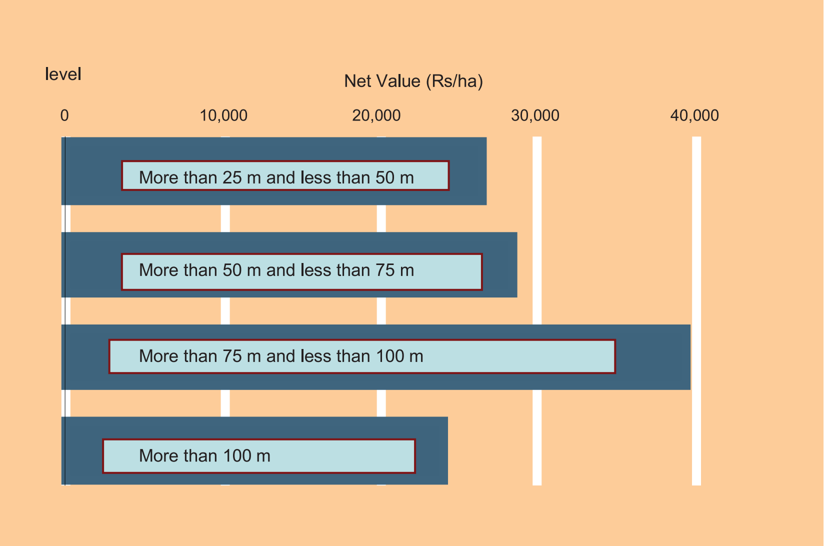
Groundwater depth also could impose constraints in the choice of crops. Our research exhibits that farmers are averse to taking risks and, as such, they prefer to grow multiple crops when there is an increase in the groundwater depth. It suggests that in regions where groundwater depth is less than 25 meters, farmers mainly grow paddy and sugarcane. As groundwater depth increases farmers cultivate different kinds of crops and particularly, cash crops for risk diversification. Then as the depth of groundwater table increases further, the crop choice of the farmers is similar to that of a rain-fed area, where they grow less-valued crops given the limited water availability in such areas.

Figure 4. Fitted relationship between groundwater depth and cost of well.



Net returns from land are also dependent on the groundwater depth. This is evident in Figure 5, which shows the average net value per hectare of land generated at different levels of groundwater. It shows that the average returns per ha of land is high when the groundwater depth lies between 75 and 100 meters and after that the average returns begin to fall. It could imply that as depth of groundwater table rises, farmers employ higher capacity

Figure 5. Average net returns at different levels of groundwater.



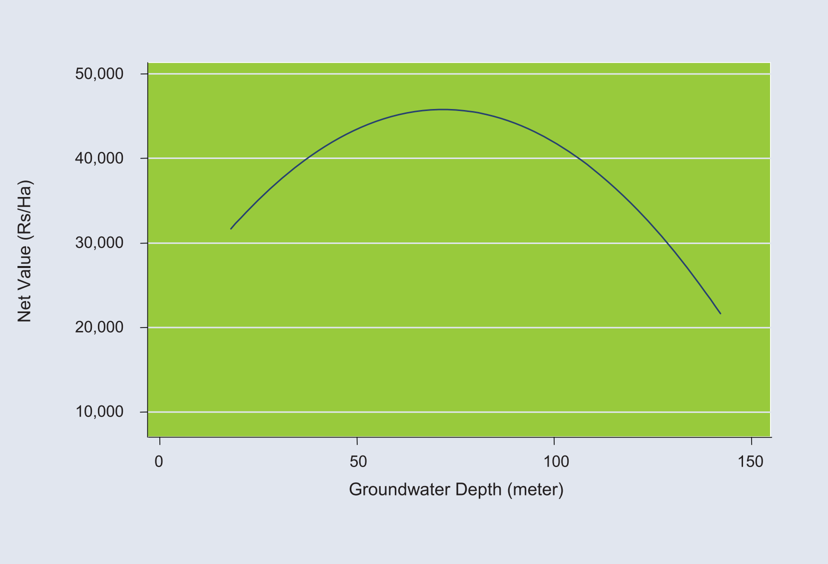
Source: Based on authors' estimates

pumps, and to recover the extra cost they grow cash crops, which allows farmers to get higher average returns.

After this, the opportunity cost of groundwater increases and farmers cannot afford costly pumps and it restricts their income at a lower level. Our analysis also suggests that with increasing groundwater depth, the yield of crops, particularly paddy, decreases. And beyond a certain depth of groundwater, the farmers find the opportunity cost of water to be high. Even though electricity is free, the high cost of groundwater extraction is very much related to the cost of operation and maintenance of the pump including higher horse power used, both of which increase with the depth of groundwater. Figure 6 reveals the fitted relationship between the yield of paddy and groundwater depth. It indicates that the yield of paddy decreases with groundwater depth when the latter is more than 65 meters. Higher groundwater depth represents relative water scarcity and therefore, restricts farmers to use less water and leads to lower crop yield .The relationship highlights the need for a sustainable use of groundwater and to avoid a situation that may constrain the productivity of crops. Hence, surface water could have a bigger role to play in regions where farmers face rising groundwater depth.

As surface water would come in, it could sustain the groundwater usage and allow farmers to get higher productivity with a lower agricultural cost for extracting water. Additional surface water can also help farmers to take more risks to invest in higher capacity pumps and adopt crop diversification in groundwater-irrigated areas, where the average depth is more than 100 meters. Given that nearly 40 % of the farmers are irrigating in areas where the groundwater depth is more than 100 meters, the benefits of the surface water irrigation could be substantial in this region.

Figure 6. Fitted relationship between yield and groundwater depth.



Present Cropping Pattern of the Polavaram Command Area

The benefits of irrigation projects depend very much on the present and future cropping patterns in the command area. From the sample survey we have tried to understand the present cropping pattern in the proposed command area and make a hypothesis of the future cropping pattern of the farmers after the advent of surface irrigation.

In the proposed command area in the right bank, the three main crops are paddy, sugarcane and tobacco. Paddy is grown mainly in the kharif season, while tobacco and sugarcane are the annual crops. In this region, the annual crops are very popular among the farmers. In the right bank command area, annual crops are grown in nearly 65 % of the cropped area, while kharif crops account for only 26 %. Sugarcane and tobacco are the two major crops among the annual crops in the right bank. During the kharif, paddy comprises more than 95 % of the area.

Why is it that the majority of the farmers grow annual crops in the region? Our survey suggests that farmers grow annual crops mainly in the groundwater-irrigated area. It could be argued that groundwater irrigation provides the kind of reliability in water supply that is needed to grow high-valued crops. Also in the case where there is no alternative source of irrigation other than groundwater irrigation, farmers rely on high-valued crops to cover the cost of groundwater extraction, mainly the cost of pumps, operation and maintenance.

In the proposed command area of the left bank, paddy, sugarcane and black gram are the major crops. Here, the dominance of annual crops is much less than in the right bank, and accounts for only 32 % of the cropped area. Sugarcane is the major crop among the annual crops. Much of the cropped area is used to grow one-season crops, and particularly paddy in the kharif.

In the downstream of the Godavari where much of the land is irrigated from the surface irrigation source, the popular crop choice of farmers is paddy. Paddy is grown in more than 90 % of the farm land having access to canal irrigation. With groundwater irrigation, the crop choice is much more diversified like in the rain-fed regions. However, with groundwater irrigation, more high-valued and water-intensive crops are grown than in rain-fed areas.

The key issue that emerges here is how the cropping pattern in the region would change after the introduction of surface water. If the farmers are growing high-valued annual crops by means of groundwater irrigation, would they shift to traditional crops like paddy with the advent of surface water or continue to grow their annual crops with groundwater irrigation? Would the farmers continue to grow-high value annual crops and increase the value of surface water or else like downstream Godavari farmers, grow paddy in both the seasons?

The answer to the issue is also related to the existing cropping pattern trend in Andhra Pradesh, which suggests a paradigm shift in the choice of crops over the past decade. Farmers are shifting from growing traditional crops to high-valued crops. Such a behavioural change in farmers was also reflected in our one-to-one interaction with them. Once the surface water reaches the Polavaram command area, the farmers may show an interest in growing annual crops as before. However, much of this change is due to the demand factor and irrigation conditions. Due to storage constraints the entire area is proposed to be irrigated mainly during the kharif season only (NWDA 1996). Given the limited availability of surface water in the rabi, the farmers may continue to use groundwater in the alternate season. The surface irrigation would help the farmers in sustaining groundwater usage during the rabi season and facilitate the growing of annual crops. The return flow factor as a fraction of surface water usage could be 10-20 %, and this additional water could be used in the rabi season in the form of groundwater irrigation (NIH 199).

Land Use Intensification

Land use intensification is another important criterion for land productivity.[2] Much of the increase in gross cultivated area in the Polavaram proposed command area has been achieved by increasing land use intensification (LUI). We explore here the following: 1) the current land use intensification in the proposed command area and 2) the factors responsible for the increase in land use intensification.

---

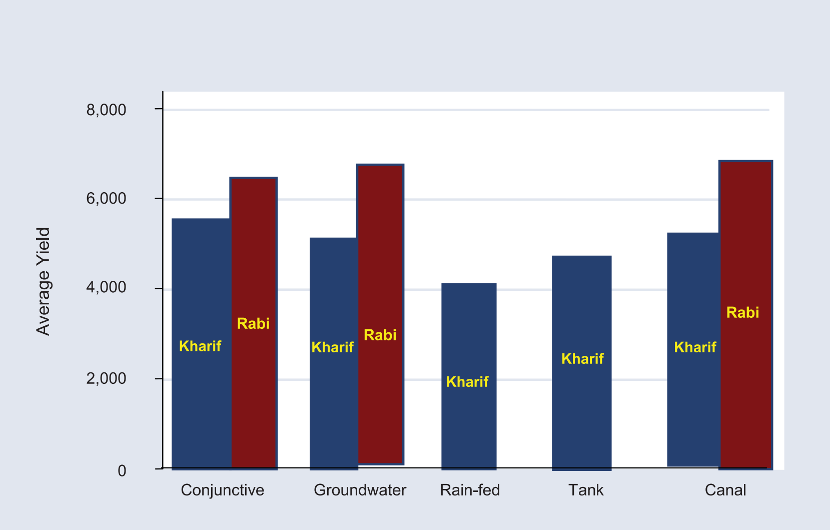
[2] There are many crops like sugarcane, banana, coconut etc., which stand for more than 3 months in the field and computing their land intensity, requires special consideration. Unlike the conventional measure of irrigation intensity, defined as the ratio of gross irrigated area (GIA) to net irrigated area (NIA), (GIA/NIA), we have computed irrigated land use intensity (ILUI) as $\frac{gia + \sum_{j}^{n} nia^{j}}{nia}$ where j is the number of annual and perennial crops, which stands for more than one cropping season in the field.

It is generally believed that surface water irrigation helps farmers to increase the intensity of land use. Our survey results also validate such a widely held hypothesis by citing that the land use intensification is at its maximum in the downstream of the Godavari, where all the cultivated area is irrigated from the surface water source. In addition, as mentioned earlier, much of the proposed command area is already irrigated and, as irrigation is one of the major drivers of the increased intensification of land use, the land use intensifications are 165 % and 110 % in the right and left command areas, respectively. Higher land use intensification in the right bank is due to the extensive cultivation of annual crops using groundwater irrigation. We investigated whether the diversion of surface water in the proposed command area would help the farmers to increase this intensity further. Our analysis suggests that surface irrigation could facilitate farmers to irrigate the rabi crops and increase the intensification of land use. If surface irrigation is limited in the rabi season, then the farmers can alternatively use the groundwater resource. Higher use of groundwater in the rabi season could be possible through surface water recharge or by being less dependent on groundwater during the kharif season.

Yield and Net Returns of Major Crops

The overall objective of a surface irrigation project is to increase the net value of land and support the livelihood of the farmer. However, it is imperative to know whether the increase in net value of cultivable land would be generated from a productivity difference or through a reduction in agricultural cost. We analyzed the difference in yield through the different sources of irrigations. Figure 7 shows the yield of paddy, one of the major crops in the region. The average yield of paddy from conjunctive water use is significantly higher than that of only using either surface or groundwater. Moreover, there is no significant difference in the yield whether the source is groundwater or surface water.

Figure 7. Paddy yields (kg/ha) in kharif and rabi seasons under different sources of water supply.



The average yield of paddy is only 2.43 % higher in farms irrigated from surface irrigation compared to what is obtained in groundwater-irrigated farmland. It implies that from a productivity point of view, we may not expect any substantial difference in the areas that are already irrigated by groundwater, even after the completion of the Polavaram Project. However, if the farmers use conjunctive irrigation, the project could lead to better productivity. The propensity of the farmers to use both groundwater and surface water is higher as the farmers in the groundwater-irrigated areas have already incurred the sunk costs of pumps. The average fixed cost would only decrease if the farmers continue to use groundwater.

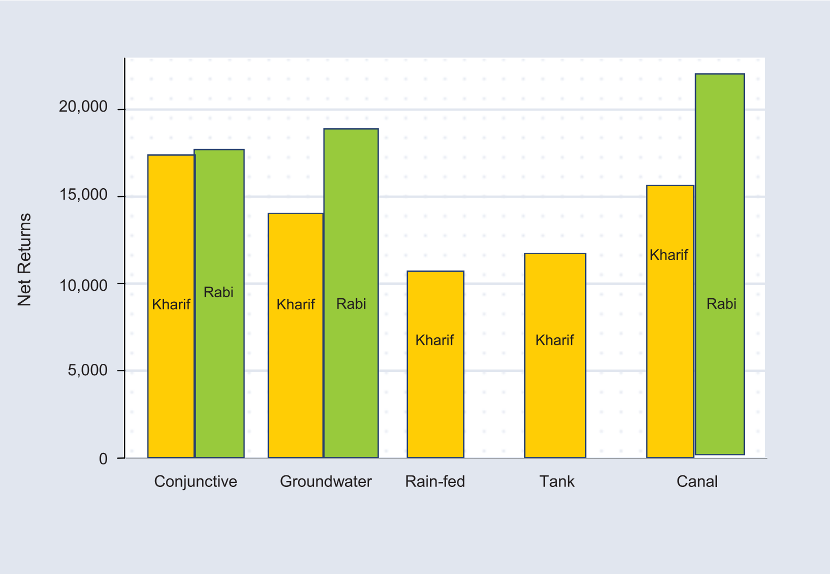
A significant proportion of the land in the proposed command area, particularly in the left canal command area, is rain-fed. Presently the rain-fed yield in the region is 1.6 tonnes per acre, and there is not much variation across the farms. However, the rain-fed yield of paddy is higher than the national average. In these areas, if the farmers grow paddy after the introduction of surface water, our analysis suggests that the productivity difference would become significant.

In the past, much of the irrigated area in the proposed command area was irrigated by ancient tanks. However, today, tank-irrigation has decreased considerably (Palanisami 1991). Tank- irrigation accounts for only 11 % of the left command area. There are several factors, which caused this decline in tank irrigation. In the last couple of decades much of the focus, priority and investment have been shifted to minor irrigation structures and mega projects. Tank- maintenance has also been neglected due to inadequate management resources. Much of the tanks in the area are rain-fed, and for the crops that are grown from tank irrigation, the yield is lower like in the rain-fed area. In the proposed command area, the average yield of tank irrigated paddy is lower than 2 tonnes per acre. So, the tank-irrigated area may also expect an increase in productivity with the proposed water transfers.

We have calculated the net return from cultivating one hectare of land in the region. The return from land is dependent on the choice of crops. As paddy is one of the major and most popular crops, we have compared the net returns of paddy across different sources of irrigation, which is illustrated in Figure 6. Figure 8 shows that net returns per ha of cultivation is high in the surface-irrigated areas in comparison to other sources of irrigation. The difference is higher mainly in the rabi seasons, for instance, net returns in the surface-irrigated area during the latter season is on average Rs. 3,000 higher than in the groundwater-irrigated area. With no significant difference in yield between the two sources of irrigation, the difference in net value can be attributed to the difference in cost due to the higher groundwater extraction cost. In regions where there is a higher depth of groundwater, the difference is even bigger. In the rain-fed area, the net return from paddy is around Rs. 10,000 per hectare compared to Rs. 44,000 per hectare annually in the surface-irrigated areas. An annual increase of Rs. 34,000 per hectare in the rain-fed area is substantial if the farmers grow paddy in both seasons. Since the major proportion of the rain-fed area is located in the left bank of the command area rather than in the right bank, much of the benefits could be reaped in the former part of the proposed command area.

We have also shown that the net value decreases with a higher groundwater depth. The increase in net returns from the groundwater-irrigated areas would be significant, provided surface water irrigation reduces the stress on groundwater irrigation or facilitates groundwater recharge. Though higher recharge helps in reducing the operation and maintenance cost of the pumps, this is still a small proportion of the total cost of groundwater irrigation. Hence, a higher recharge from surface irrigation would increase the net returns from the groundwater irrigated areas in a limited way. However, there is a possibility that a proportion of the current groundwater irrigated

Figure 8. Net returns from paddy production from different sources of water supply.



area could become unsustainable and thereby inappropriate to use, if the farmers continue to exploit the groundwater resource. Without the Polavaram Dam, these areas could well turn into rain-fed areas, as a result of the opportunity cost of groundwater extraction exceeding the economic benefits. The Polavaram Dam, by diverting surface water can create an opportunity for these farmers to rely more on surface irrigation and thereby sustain their agricultural livelihood.

Benefits of Irrigation

Irrigation benefits from the water diversion at the Polavaram Dam is to a certain extent subjective and depends on several factors .Given the ex ante characteristics of the project, the best approach would be to analyse the different plausible scenarios. We attempt to assess the possible irrigation benefit from the water diversion at the Polavaram Dam under four alternative scenarios. We have constructed several scenarios mainly based on the different cropping patterns that the farmers may adopt after the advent of surface water irrigation by the Polavaram Dam.

In the first scenario, we have taken the proposed cropping pattern as suggested by the Andhra Pradesh Environmental Impact Assessment Report (Gujja et al. 2006). A similar cropping pattern is suggested for both the left and the right bank command area. The report suggests that paddy would be grown in the kharif season followed by pulses in the rabi. The report also indicates that the farmers would grow sugarcane and chillies as annual crops.

In the given cropping pattern, although the yield of paddy in the rabi is higher than that of the kharif, pulses have been proposed as a crop choice instead of paddy during the rabi. This could be to reduce the stress on the water demand during the dry season.

In the second scenario given the present popularity of growing maize during the rabi in Andhra Pradesh, we assume that the farmers may grow high-valued maize instead of pulses in the rabi season.

Again, high-valued cash crops like tobacco and sugarcane are grown in the region as annual crops with the help of groundwater irrigation. The farmers have already invested in high sunk cost and they are unlikely to shift completely to surface water irrigation unless the state government imposes a tariff on electricity for groundwater extraction. Under the prevailing circumstances, the farmer may continue to grow these high-valued annual crops even after the completion of the Polavaram Project.

When constructing these scenarios we have also considered the sustainability of groundwater. Our sample survey's results indicate that without the Polavaram Dam it may be difficult for the farmers to continue groundwater extraction in the right canal command area. We have assumed that without the water diversion from the Polavaram Dam, there could be a 25 % reduction in the present groundwater irrigated area. This assumption could be reasonable in that in much of the groundwater-irrigated area of the proposed right canal command area, the depth of the water table is more than 100 meters. The four scenarios constructed are described in Table 1.

Table 1. Scenario description.

Scenario	Description
Scenario-I	Proposed cropping pattern from the Andhra Pradesh Environmental Impact Assessment Report: Paddy-Kharif: Pulses Rabi: Annual crops: Sugarcane and chillies.
Scenario-II	Different cropping pattern - Paddy-Kharif: Maize Rabi: Annual crops: Sugarcane and chillies.
Scenario-III	Present cropping pattern for annual crops
Scenario-IV	25 % reduction in groundwater-irrigated areas in the right canal command area

Table 2. Benefits from irrigation.

	Scenario I	Scenario II	Scenario III	Scenario IV
Annual increase in the value of the crop output (in crores)-Left bank	236.34	276.81	325.60	236.34
Annual increases in the value of crop output (in crores)–Right bank	83.42	141.61	127	146.16
Annual increase in the value of crop output (in crores)– in the total command area	319.76	418.43	452.60	382.50
With multiplier effects (20 %)	383.71	502.11	543.12	459.00
Increase in value (Rs.) per cubic meter of water	0.77	1.00	1.09	0.92

Using the estimated cropping pattern, irrigated area and the net value of crops per ha, we have estimated the total value of the agricultural benefits of crops before and after the completion of the Polavaram Project, for both the right and left command areas. Table 2 shows the possible irrigation benefits from the Polavaram Dam.

The overall annual increase in value of crop per cubic meter of water ranges from Rs. 0.77 to Rs. 1.09 under alternative scenarios. Assuming the cropping pattern proposed by the Andhra Pradesh Environmental Impact Assessment (APEIA) report, the annual increase in the net value of crop output would be 319.76 crores; while taking into account a multiplier effect of 1.20, the overall benefit inclusive of indirect benefits stands at 383.71 crores under the same scenario.

The study indicates that the benefit would be at a maximum of Rs. 1.09 per cubic meter if the farmers continue to grow annual crops, particularly in the right bank canal command area. And the benefit would be at a minimum of Rs. 0.77 per cubic meter of water under the scenario proposed by the Andhra Pradesh Environmental Impact Assessment Report. However, if the farmers grow maize instead of pulses during the rabi season, the benefit will increase to Rs. 1 per cubic meter of water.

The study suggests that the viability of the project depends a lot on the choice of the cropping pattern. If the farmers continue to grow high-valued annual crops with additional surface water, then the benefit would be substantial. As noted earlier, right bank canal command area is part of the river linking project. Since the right bank command area is already irrigated, our analysis suggests that there is insufficient room to increase the economic benefits any further. On the contrary, the annual increase in the value of output could be much higher in the left bank canal command area than in the right bank, where the proportion of rain-fed area is larger. However, benefits for the right command area would increase by 70 % if we assume that the present trend of groundwater growth may not continue and there would instead be a 25 % reduction in the present groundwater irrigated areas.

Livestock Benefits

Livestock is an important source of livelihood in the region. Of the farmers surveyed in the command area, about 66 % possess livestock, which mainly includes cattle and buffalo. Animals are heavily dependent on water largely because of its use for their feed production- an estimated 400 cubic meters or more of water is used per year for the maintenance of livestock. The total water needed may be more than double this amount, with drinking water being less than 2 % of what is required for feed production.We investigated how the livestock population would benefit through the introduction of surface water in the region.

Animal densities are strongly correlated with human densities and are highest in areas of intensified agriculture, especially in and around irrigation systems. In the proposed command area, which is largely irrigated, the proportion of livestock in the region is much less, and one possible reason could be the higher application of tractors and mechanical devices, which reduces the demand for bullocks.

However, an important observation that emerged from our study is that the density of livestock is higher in the rain-fed areas. The number of buffaloes per hectare in the rain-fed area is higher than that in the irrigated areas. In the rain-fed areas, livestock provide a steady source of income for the farmers thereby reducing the variability of income. An important hypothesis is that with the advent of surface irrigation, farmers may invest their effort more in agriculture and retain less livestock.

In our study we have also highlighted another relevant issue, i.e., whether surface irrigation would help increase the milk production of the livestock. Our survey suggests that the milk production of buffalo and cattle are 20 % and 32 % higher, respectively, in the surface irrigated area than in the rain-fed area (see Figure 9). The likely reason for this could be that surface irrigation provides farmers an opportunity to grow fodder as second crop and this generates extra biomass for application to livestock. Hence, with more surface irrigation after the completion of the Polavaram Dam, it could be possible for the farmers to feed their livestock better and increase the latter's milk production. In calculating the net economic returns, we have also analyzed the fodder cost for livestock. The fodder comprises dry fodder, green fodder and concentrates. Concentrates account for more than 50 % of the total fodder cost for both cattle and buffaloes, while green fodder accounts for 40 %. The results indicate that in rain-fed areas with a lower production of fodder, the farmer may have to buy fodder, which can in turn contribute to increasing the marginal cost of milk production.

Figure 9. Milk productivity in areas with different sources of water supply.

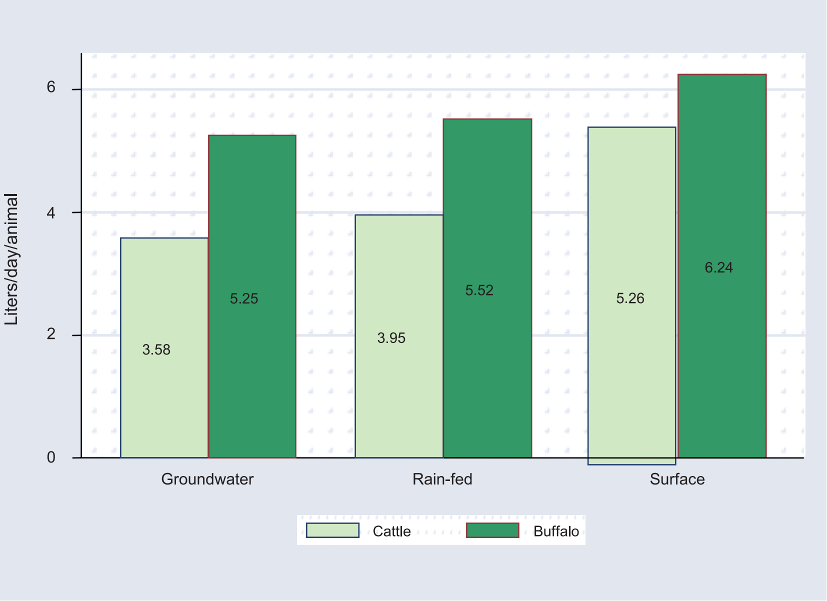


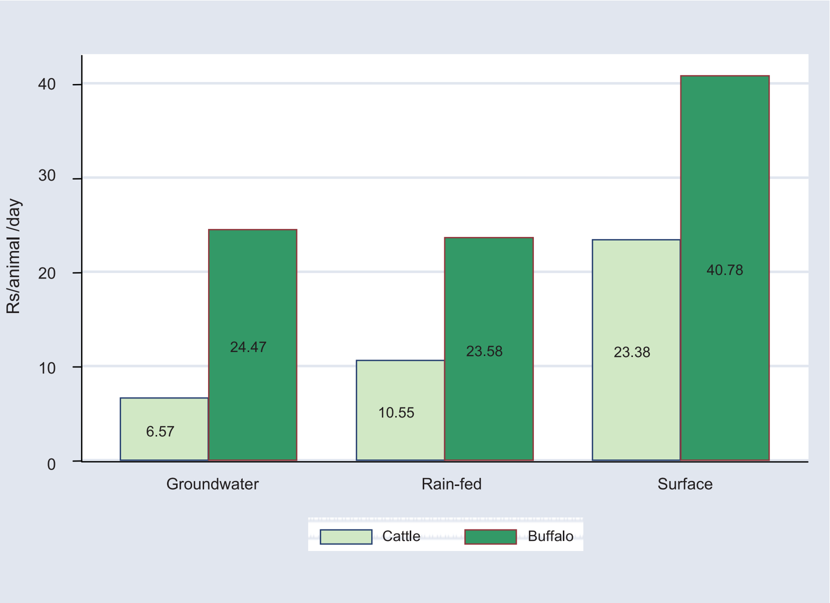
Figure 10 suggests that the net value of milk production (cattle and buffalo) per day in the surface irrigated area is 121 % and 72 % higher for cattle and buffalo, respectively, than that in the rain-fed area. The net gain is Rs. 40.78 per day from a buffalo in a surface irrigated area.

The net value of milk production from a buffalo is also much higher than that of a cow across all sources of irrigation, and that is why farmers prefer to keep buffaloes instead of cattle. In groundwater irrigated areas, for instance, the net value of a buffalo is 72 % higher than that of a cow, but it is only 44 % in the surface irrigated areas.

As the density of livestock is higher in the rain-fed areas, particularly for buffaloes, the net value of a buffalo per hectare in the rain-fed area is similar to that of one in the surface irrigated area, but 23 % higher than that of one in the groundwater irrigated area (Figure 11).

We attempted to assess the livestock benefits from the Polavaram Dam under several alternative scenarios. In our analysis, we found that the number of livestock per hectare is

Figure 10. Net returns per day from milk production in areas with different sources of water supply.



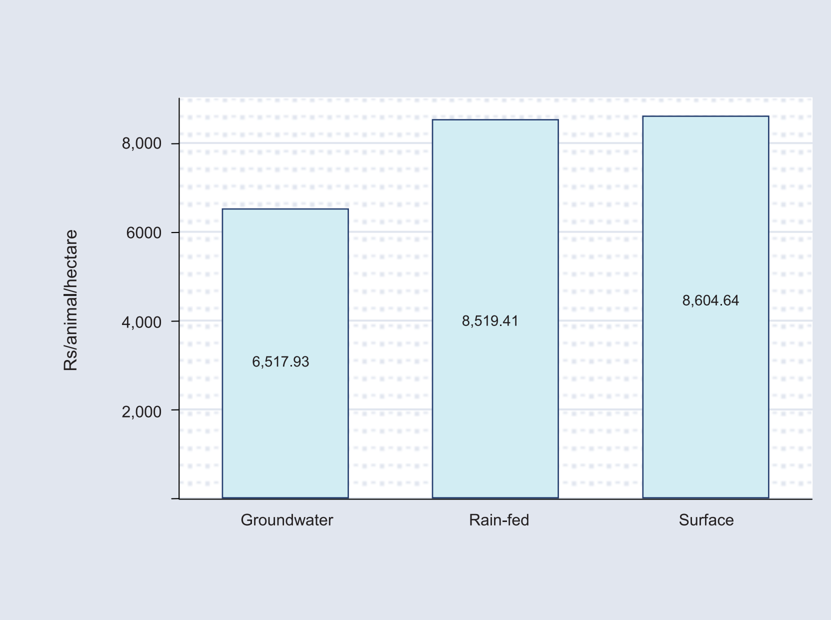
much higher in the rain-fed areas than in the irrigated area, which resulted in a higher net value per hectare. With the advent of surface irrigated water from Polavaram, farmers in the rain-fed area may retain the livestock that is currently providing a continuous income to sustain their livelihood. Farmers may also however, overall retain less livestock with the introduction of canal water and engage themselves more in agricultural activities. In another scenario we have considered a case where there could be a 10 % reduction in fodder cost due to higher fodder production in the irrigated area.

The results are shown in Table 3. It indicates that in scenario I, where farmers could be less interested in retaining livestock after surface irrigation, the net gain would be 10 %. However, if the farmers retain their livestock in scenario II, the gain could rise to 45 % more than at present. In scenario III, the 10 % reduction in fodder cost could result in a yearly gain of 45 crores after the advent of surface water from Polavaram. Livestock can increase the overall benefits of the Polavaram Dam by 8 to 32 %, depending on the different scenarios. The gains would be at their maximum if the farmers grow maize for fodder in the rabi season and retain their livestock.

Table 3. Net gain in milk production benefits after Polavaram water transfers.

Scenario	Scenario	Net Gain	Net Gain (%)
I	Farmers will retain less livestock in surface irrigated area after Polavaram	Rs. 25 Crores	10 %
II	Farmers will retain their livestock in surface irrigated area after Polavaram	Rs. 103 Crores	44.83 %
III	10 % reduction in fodder cost	Rs. 45 Crores	19 %

Figure 11. Per hectare net returns from buffalo milk production in a year.



Conclusion

In this paper we made an attempt to analyze the possible irrigation benefits from surface water augmentation through river linking. The paper illustrates a component of the river linking project of India – the Godavari-Krishna Link at Polavaram. In this proposed link command area, groundwater is the most dominating form of irrigation. This is not in isolation from the national context of India, where groundwater has already been established as the major source of irrigation over the last two decades.

The research paper attempts to address the question – how additional surface irrigation facilities could help farmers to increase agricultural productivity in much of the already irrigated area. In the light of such a premise, our research finds that there is no significant difference in the yield obtained using either groundwater or surface water. Moreover, with electricity usage (which generally forms the major part of the groundwater extraction cost) being subsidized for farmers, there may not be any substantial difference in the agricultural cost .Hence, our study suggests that the irrigational benefits in the command area could be much lower compared to other command areas, as much of the cultivated area in the proposed command area is already irrigated from the groundwater source.

In the region, the growing concern is about groundwater overexploitation and falling groundwater tables in the proposed command area. Results indicate that the yield (paddy) and net returns decrease dramatically as the groundwater depth increases.

Could surface water diversion from the Polavaram Dam be useful in sustaining the groundwater resource where the average depth of groundwater tables is more than 100 meters in 12 % of the proposed command area? The surface irrigation could help the farmers in sustaining water usage during the rabi season and can facilitate the growing of annual crops. The return flow factor as a fraction of surface water usage could be used in the rabi season in the form of groundwater irrigation. Added to this, there will be a lesser dependency on groundwater in the kharif season. Hence, surface water would help in recharging groundwater and reduce the high groundwater extraction cost in the regions, particularly in the region where, at present, the depth of the groundwater table is more than 100 meters. As the depth of the groundwater tables decreases with the help of surface water recharge, it could also help farmers to increase the yield and net value of crops.

Moreover, as the farmers in the groundwater-irrigated areas have already incurred the sunk costs of pumps, they are more likely to use both groundwater and surface water conjunctively. It could bring them further benefits as the average yield of paddy from conjunctive use of groundwater and surface water is much higher than that what is achieved by using either surface or groundwater.

Benefits of a surface irrigation project also depend largely on the crop choice of farmers. Currently there is a popular trend among the farmers to grow high-valued annual crops, mainly in the groundwater irrigated areas. We have demonstrated that higher benefits from the Polavaram Dam could be reaped if the farmers continue to grow annual crops. Such a scenario would have a higher benefit: cost ratio of investments that might be more favorable for the implementation of the project.

Livestock is an important source of income to the livelihood of farmers. The study also attempts to assess the livestock benefits that may be generated from the water diversion at Polavaram. Livestock can increase the overall benefits of the Polavaram Dam by 8 to 32 % depending on the different scenarios. The study shows that livestock benefits will be substantial if the farmers retain their livestock even after the introduction of surface water or with a reduction in fodder cost. The gains will be at their maximum if the farmers grow maize for fodder in the rabi season and retain their livestock.

References

Amarasinghe, U. A.; Sharma, B.R.; Aloysius, N.; Scott, C.; Smakhtin, V.; Fraiture, C.D.; Sinha, A.K.; Shukla, A.K. 2005. *Spatial variation in water supply and demand acrossrRiverbBasins of India.* Research Report 83. Colombo, Sri Lanka: International Water Management Institute.

Barbier, E.B. 2004. 'Water and Economic Growth'. *Economic Record* 80:1-16.

Bhaduri, A. 2005. Political altruism of transboundary water sharing in PhD Dissertation *Transboundary water sharing between an upstream and downstream country* University of Wyoming.

Dhawan, B. 1993. 'Indian Water Resource Development for Irrigation: Issues, Critiques and Reviews'. New Delhi, India: Commonwealth.

EPA. 1995. 'A framework for measuring the economic benefits of groundwater' EPA 230-B-95-003 Washington D.C., USA.

Gujjas, B.; Ramakrishna, V.; Sivaramakrishna eds. 2006. 'Perspectives on Polavaram-A Major Irrigation Project of Godavari', New Delhi, India: Academic Foundation.

Howe, C W.; Schurmeier, D. R.; Shaw, W. D .1986. 'Innovative Approaches to Water Allocation: The Potential for Water Markets'. *Water Resource Research* 22 (4): 439-448.

Narayanamoorthy, A.; Deshpande, R. S. 2005. ’Where Water Seeps Towards a New Phase in India’s Irrigation Reforms’. New Delhi, India: Academic Foundation.

National Institute of Hydrology. 1999. ‘Hydrological problems of hard rock region –A state of art report’. *Jal vigyan Bhawan Roorkee* 247667

Ncube, M.; Taigbenu, A.E. 2006. ‘The Institutional Challenge in the Implementation of Water Demand Management: A Case of the City of Bulawayo, Zimbabwe’. *Environmentally Sound Technology in Water Resources Management*

NWDA. 1999. Feasibility Report of Polavaram Vijayawada Link, Government of India. http://nwda.gov.in/index3.asp?sublink2id=33&langid=1

Palanisami, K. 1991 ‘Conjunctive Use of Tank and Well Water in Tank Irrigation System. In *Future Direction for Indian for Indian Agriculture: Ressearch and Policy Issues,* eds. Ruth Meinzen Dick and Mark Svendsen. India Collaborative Programme, IFPRI.

Rijsberman, R .Frank. 2006. Water Scarcity: Fact or Fiction? *Agricultural Water Management* 80 (1-3): 5-22.

Saleth R. Maria. 2001. ‘Water Pricing Potential and Problems’. *2020 Focus,* October 9, 2001.

Singh, S. 2002. Taming the Waters: The Political Economy of Large Dams in India. New Delhi, India: Oxford University Press.

Benefit of Irrigation Water Transfers in the National River Linking Project: A Case Study of the Ken-Betwa Link

Upali A. Amarasinghe[1], Om Prakash Singh[2], Tushaar Shah[1] and
Ravindra Singh Chauhan[3]
[1] International Water Management Institute, New Delhi, India
[2]Benaras Hindu University, Varenasi, India
[3]Chattrasal Seva Sansthan, Jhansi, India

Introduction

Ken-Betwa, a multipurpose water development project, is one of the smallest components of the proposed National River Linking Project (NRLP) of India. The NRLP envisages transferring 178 km^3 of water across 37 rivers, through a proposed network of about 30 river links, 3,000 storages and 12,000 km long river links and canals. It is expected to cost about US$123 billion (in year 2000 prices). The NRLP has two main components: 1) the Himalayan component with 14 river links; and 2) the peninsular component with 16 river links. The Ken-Betwa Project (KBP) is an independent link in the peninsular component that connects two small north-flowing rivers namely, the Ken and Betwa rivers in the Greater Ganga Basin. The KBP plans to transfer 3,245 million m^3 of water, which is only 1.8 % of the proposed total water transfers of the NRLP. The cost of the KBP, which is estimated at US$ 442 million is only 0.36 % of the total NRLP cost.

Although it is a small independent link in the overall NRLP plan, the KBP also has many critiques. Alagh (2006) pointed out that inadequate attention has been given to cropping patterns and their suitability to the region. Chopra (2006) commented on the inadequacy of the project planning to meet different scenarios of future water resources development needs; Thakkar and Chaturvedi (2006) criticized that: a) the feasibility study has inadequate water balance studies; b) there was a lack of participation of local people in the decision-making process of project planning; c) there was a failure to utilize the existing infrastructure to its optimum; d) there was a lack of alternative options analysis; and e) subsequently there are not enough benefits to outweigh the cost. Patkar and Parekh (2006) commented on social displacement, rehabilitation and resettlement and environmental issues, while Mohile (2006) focused on the scope for improvements and the actual feasibility of project when assessing the feasibility reports of KBP.

The irrigation component dominates the KBP. The cost of the project, excluding the hydropower component, is estimated at US$431 million, which is 98 % of the total estimated cost for the project. The KBP expects to provide irrigation for 0.49 million ha. In the process it expects to recharge groundwater to irrigate a substantial part of the non-command area. The primary objective of this paper is to assess the direct and indirect economic benefits of the additional irrigation water transfers of the KBP. But first, we assess a major contentious issue of the project i.e., the compatibility of the proposed cropping patterns vis-à-vis the past trends and existing cropping patterns in the KBP area. Next, we assess the direct economic benefits such as the increase in the net value added to crop production and livestock output in the command area. We also assess, though not in detail, the indirect benefits, such as the benefits generated through groundwater recharge and irrigation in and outside the command area, forward linkages (storage, transport and agro-processing), and backward linkages (agricultural farm equipment supplies and services). We assess the net value added benefits of the irrigation water transfers under different cropping patterns, and also assess the demand for irrigation water in relation to the envisaged water transfers.

The rest of the paper is organized into six sections. Section two, which follows next, briefly describes the KBP project location, its components and the envisaged benefits. Section three outlines data collection for different analyses, while section four begins the proper analysis. It compares the proposed cropping patterns with past trends and the existing cropping pattern, and discusses the changing pattern of crops in the region. Section five assesses the direct irrigation benefits of new irrigation water transfers in the command area. We conclude the paper with recommendations for revisiting the project plans in the preparation of detailed project report of KBP.

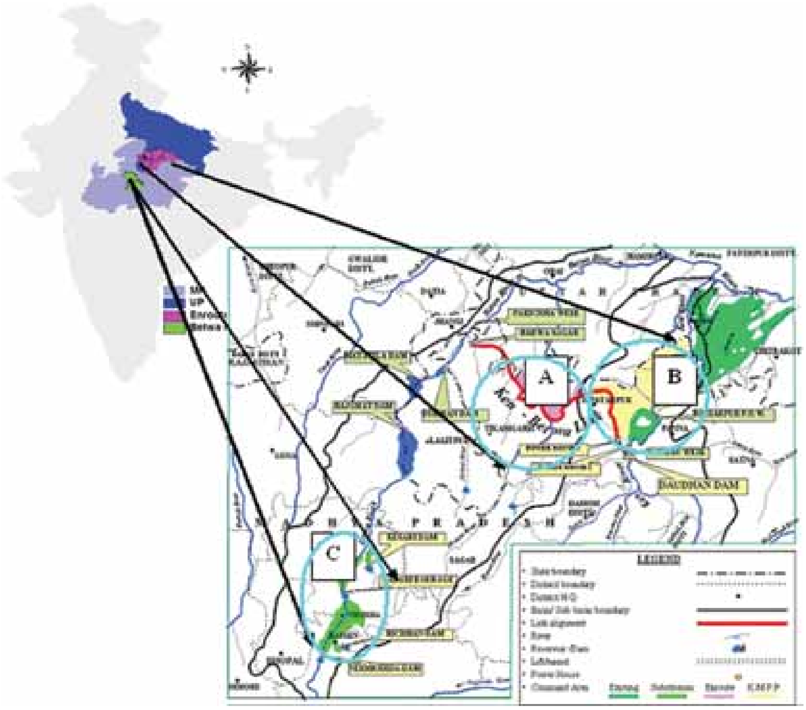
Ken-Betwa Project – Location and Proposed Irrigation

The KBP is located in the Bundelkhand region of Madhaya Pradesh and Uttar Pradesh in India. The KBP envisages the construction of a dam at Daudhan, a location upstream of the Periccha Weir in the Ken River (Figure 1), and then, will divert the Ken River water from this reservoir through a canal to the Betwa River. The KBP has three irrigation components. It proposes to provide irrigation to:

- en route command area of the link canal (A in Figure 1);
- downstream area of the Ken River (B in Figure 1); and
- transfer water to downstream areas of the Betwa River by substituting the irrigation demand of the upper reaches of the Betwa River (C in Figure 1).

Seven districts in Bundelkhand region cover the KBP command area (Figure 1). The en route command of the link canal falls inside Tikamgarh and Chhatarpur districts in Madhya Pradesh and Jhansi and Hamirpur in Uttar Prdesh. The Ken Multi-Purpose Project (KMPP), proposed previously by the Government of Madya Pradesh, falls inside Chattarpur and Panna districts in Madhya Pradesh. The Betwa command, which consists of four projects namely, Barari, Richhan, Neemkheda and Kesari, is located in the Raisen and Vidisha districts in Madya Pradesh.

Figure 1. Ken-Betwa Project index map.



Source: The Ken-Betwa project index map is from the feasibility report (NWDA 2005)

Generally, the Bundelkhand region, experiences highly variable inter- and intra- annual rainfall (Table 1). Average annual rainfall of the seven districts exceeds 950 mm every 2 out of 4 years (50 % dependability rainfall), and exceeds 640 mm every 3 out of 4 years (75 % dependability rainfall). Four monsoon months (June- September) receive more than 90% of the annual rainfall. Thus the kharif (or the wet) season (June- October) requires hardly any irrigation for many of the crops. But irrigation demand is high in the rabi (dry) season (November-March), with annual potential evaporation of the region at 1,690 mm.

A major goal of KBP is to provide irrigation to the water -scarce Bundelkhand region. The en route command, which falls under the NRLP, irrigates only 7 % of the total command area of the KBP (Table 2), and accounts for 10 % of the irrigation supply. The KMPP command has 65 % of irrigated area, accounting for 70 % of the irrigation supply. The KMPP suggests irrigating:

- 84 % and 83 % in the en route command;
- 60 % and 74 % in the Ken command; and
- 47 % and 73 % in the Betwa command

in the kharif and rabi seasons, respectively. It is interesting to examine these suggestions, given the patterns of rainfall, past trends of growth of irrigated area, and present irrigation

Table 1. Monthly 50 % and 75 % dependable rainfall and potential evaporation.

Districts	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	June-Sept.	Annual
	P50[1] (mm)													
Harmirpur	11	4	3	0	1	61	257	286	144	14	0	1	748	782
Jhansi	10	1	2	0	0	58	269	314	155	10	0	0	795	820
Chhatarpur	13	3	2	0	0	76	315	375	163	12	0	1	930	961
Tikamgarh	12	2	2	0	0	67	301	349	157	11	0	0	874	901
Panna	14	4	3	1	1	92	338	388	173	11	0	1	991	1,026
Raisen	8	2	1	0	1	108	374	442	218	13	1	0	1,143	1,170
Vidisha	10	2	1	0	0	92	319	395	151	8	1	0	957	980
Average	11	2	2	0	1	79	310	364	166	11	1	1	920	949
	P75[1] (mm)													
Harmirpur	4	1	1	0	0	28	190	205	94	3	0	0	517	525
Jhansi	3	0	0	0	0	24	180	226	97	2	0	0	527	532
Chhatarpur	4	0	0	0	0	36	227	276	105	2	0	0	644	650
Tikamgarh	4	0	0	0	0	30	203	253	98	2	0	0	585	591
Panna	4	1	0	0	0	46	252	292	114	2	0	0	704	711
Raisen	2	0	0	0	0	66	271	336	135	2	0	0	807	812
Vidisha	3	0	0	0	0	52	225	290	84	1	0	0	651	655
Average	3	0	0	0	0	40	221	268	104	2	0	0	634	639
	ETp[1] (mm)													
Harmirpur	72	95	162	210	247	217	134	127	122	122	84	67	599	1,659
Jhansi	76	99	160	206	247	211	135	122	127	127	88	69	596	1,668
Chhatarpur	79	101	163	205	246	202	126	117	121	125	90	73	567	1,649
Tikamgarh	80	102	163	207	247	206	129	117	124	127	92	73	576	1,669
Panna	79	101	162	205	244	199	122	116	118	122	88	72	555	1,628
Raisen	97	121	183	227	278	202	123	108	124	133	105	88	557	1,788
Vidisha	94	117	180	224	274	207	126	108	126	134	102	85	566	1,778
Average	83	105	168	212	255	206	128	116	123	127	93	75	574	1,691

Source: Climate and Water Atlas (IWMI 1998)

Notes: 1 – P50 and P75 are respectively 50 % and 75 % exceedence probability dependable rainfall. ETp is the potential evapotranspiration.

land-use patterns in the Bundelkhand region. We examined the compatibility and realistic nature of the proposed irrigation pattern in both the kharif and rabi seasons in the KBP command, which also provided interesting insight in terms of cropping patterns too. The KBP proposes paddy as a major irrigated crop in the kharif season (Table 3), which consists of 18 % of the annual gross irrigated area, but 41 % of the kharif irrigated area. To what extent the past or current cropping patterns in the command area figure in determining cropping patterns for the project is indeed an intriguing question, and one which we examine in detail in a later section.

Table 2. Net and gross irrigated area (1,000 ha) and irrigation supply (million m^3) in theKBP command.

Component in KBP command	Net irrigated area (1,000 ha)	Gross irrigated area (1,000 ha) karif season	rabi season	Perennial crops	Total	Total irrigation supply
En-route command	27.0	22.6	22.2	1.9	46.7	312
Ken command	241.3	144.7	178.5	0.0	323.2	2,225
Betwa command	102.0	48.2	74.8	3.8	126.7	659
Total	370.3	215.5	275.5	5.7	496.6	3,196

Source: KBP feasibility report (NWDA 2006)

Table 3. The proposed cropping patterns in the KBP command area.

Season	Crop	Crop area (percent of gross irrigated area) En-route	Ken	Betwa	Total
Kharif	Paddy	32	15	20	17.8
	Jowar/bajra/maize	6	6	4	5.5
	Pulses	2	11	5	8.7
	Oilseeds	4	9	6	7.7
	Vegetables	2	4	2	3.1
	Fodder	2		1	0.4
Rabi	Wheat	32	34	40	35.1
	Pulses	4	12	10	10.7
	Oilseeds	4	7	5	6.5
	Vegetables	4		4	1.4
	Fodder	4	2	0	1.8
Perennial	Sugarcane	4		3	1.1
Total		100	100	100	100

Source: KBP feasibility report (NWDA 2006)

The assessment in this paper, on estimating the benefits of the proposed irrigation water transfers, uses data from many sources. We assess the compatibility of the proposed cropping patterns in comparison to the past trends using the time series data of land use and cropping patterns from 1970-1997 in seven districts covering the command area. Data on various aspects of Indian agriculture at the district level compiled by ICRISAT, and Hyderabad is the source for time series data (ICRISAT 2000). A primary survey conducted en route and in the KMPP command areas, assesses the differences of proposed cropping patterns by the NWDA feasibility report and those found presently on the ground. It also assesses the net value of benefits in existing irrigated and unirrigated command areas, and the differences between these are then used for assessing the benefits of proposed irrigation transfers in the KBP.

The primary survey, stratified according to land-use patterns, consists of a random sample of 1,000 farmers—20 farmers each from 50 villages. Selected villages for the survey fall within the two command areas, a rough indication of locations for which is available in the index map (Figure 1). Villages were selected to represent head, middle and tail sections, and also the existing surface and groundwater irrigated areas and the rain-fed area in the KBP command (Table 4).

Table 4. Composition of the sample in proposed KBP command.

Land-use patterns	Total	Distribution among districts				
		Jhansi	Tikamgarh	Chhatarpur	Harimpur	Panna
Canal irrigation	320	40	40	220	0	20
Groundwater irrigation	180	20	20	100	20	20
Rain-fed	500	20	60	360	20	40
Total	1,000	80	120	680	40	80

A questionnaire survey collected socioeconomic data from farmers' households; information of landholdings and their tenure patterns; details of cropping patterns; inputs and crop outputs; and irrigation water-use patterns for the largest parcel in the landholdings. Sub-samples in different land-use patterns fairly represent the situation at the district level. More than 52 % of the sample consists of small or marginal landholders, and about 16 % of farmers have medium or large landholdings (Table 5).

Table 5. Distribution of parcel sizes between different land-use patterns.

Land use patterns	Distribution of sampled parcel sizes (%)					
	Marginal	Small	Semi-medium	Medium	Large	Total
	0-1 ha	1-2 ha	2-4 ha	4-10 ha	>10 ha	
Canal irrigation	20	32	29	17	2	100
Groundwater irrigation	19	35	36	8	1	100
Rain-fed	13	39	32	14	2	100
Total sample	16	36	32	14	2	100

Irrigation Trends in the KBP Command

A major increase in the cropped area in the Bundelkhand region in the past was due to increased irrigation in the rabi (dry) season. We assessed the trends of area expansion using time series data of cropping patterns in seven districts covering the KBP (Table 6). Although growth in the irrigated area in the kharif season was negligible, growth in the crop irrigated area and the net irrigated area were very much similar in the rabi season. In fact, irrigation has contributed to virtually all the increases in the cropped area in the rabi season since 1970, which is more than four times the increase in the cropped area in the kharif season. However, irrigation was not a significant factor in the increase of the crop area in the kharif season. Why has irrigation not

Table 6. Trends of cropped and irrigated area in the KBP command area districts.

	Trends of cropped area and net irrigated area				
Item	Units	1970	1980	1990	1997
Net sown area	1,000 ha	2,597	2,649	2,792	2,976
Cropped area - kharif	1,000 ha	786	930	1,076	1,024
Cropped area - rabi	1,000 ha	1,670	1,678	1,909	2,131
Net irrigated area	1,000 ha	342	405	727	1,151
Irrigated area - kharif	1,000 ha	5	6	6	31
Irrigated area - rabi	1,000 ha	337	400	721	1,111
Cropping intensity	%	108	110	115	122
Irrigation intensity	%	104	102	103	104
Net irrigated area under different sources of irrigation					
• Canals[1]	%	48	38	37	24
• Tanks[1]	%	3	2	2	2
• Groundwater[1]	%	46	54	47	59
• Other sources[1]	%	3	6	14	15

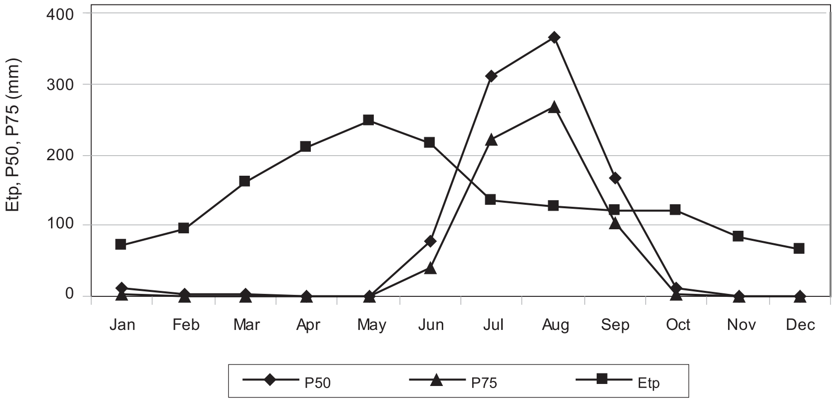
Source: ICRISAT 2005

contributed to increase the irrigated area in the kharif season? In this regard, it is important to note a few interesting facts in the increase of the crop area in this region (Table 3).

First, the cultivated area in the kharif season is only a small part of the cultivable area in the Budelkhand region, and the net sown area consists of a substantial part of the cultivated area of the rabi season. In fact, the difference between net sown area and the cropped area in the rabi season shows that only a small part of the cultivable area was cropped more than once in this region. Was inadequate soil moisture a constraint for the cultivation of crops in the kharif season? Interestingly, average rainfall, and for that matter the 75 % dependable rainfall, of 3 months of the kharif season (July, August, and September), are significantly higher than the potential evapotranspiration over the same period (Figure 2). So, inadequate soil moisture is not at all a constraint for many of the crops in the kharif season.

However, many other factors could have contributed to lower the crop area in the kharif season. Some farmers keep the area fallow in the kharif season in preparation for wheat crop cultivation in the rabi season. The Bundelkhand region produces some of the best wheat varieties in northern India. In general, wheat cultivation provides household food security fetching high prices or at least an assured income from the minimum price support system. In some areas with black soil however, the kharif crop cultivation is not suitable because of the extreme soil moisture conditions. Another possibility is that rainfall and the available irrigation resources are not adequate for long duration crops such as paddy and sugarcane in the kharif season. But, as we see in a later section, the net value of outputs of short duration crops, such as pulses and oilseeds are as high as the net value of paddy in the KBP area. It seems therefore, that farmers in the Budelkhand region prefer to use rainfall in the kharif season to grow short duration crops with higher returns.

Figure 2. Potential evapotranspiration, and 50 % and 75 % exceeding probability rainfall in command area.



Source: IWMI Water and Climate Atlas (IWMI 2000)

Second, the irrigation development in the past has only contributed to increase the irrigated area of the rabi season. In fact, the growth of the irrigated area in the rabi season has contributed to 96 % of the growth of the total net irrigated area during 1970-1997 (Table 6), and of the total irrigation in 2006, more than 99 % was during the rabi season (Table 7). Was inadequate access or control of water the reason for the low irrigated area in the kharif season? Some studies show inadequate availability of water as a key factor for low irrigation intensity in the Bundelkhand region (Bharatndu et al. 998; NWDA 2006). However, our survey shows that farmers, even in the groundwater command areas do not use irrigation for any crops in the kharif season. In fact, about 60 % of farmers in the irrigated command area use groundwater. Given the control of irrigation application, it is reasonable to assume that farmers would have irrigated at least the groundwater irrigated area in the kharif season, had there been a deficit of soil moisture for their crops. But the data shows almost all farmers did not irrigate their parcels during the kharif season in the proposed KBP command area. This is true even in the parcels in the canal command areas. In the KBP, rainfall adequately meets the water requirements of current cropping patterns. And as mentioned before, farmers in the KBP seems to prefer oilseeds and pulses in the kharif season as they fetch higher net returns, and also require less water.

Given these trends, one possibility, and, in fact, a very likely scenario is that farmers would not irrigate their parcels in the command area in the kharif season even with the availability of more water from the proposed irrigation transfers. Did the feasibility study of the KBP (NWDA 2006) take into account the past trends or the present status of irrigation patterns in the command area for designing the cropping patterns, and estimating the subsequent irrigation demand? It seems, not. In fact, quite contrary to the current cropping patterns, the feasibility report proposes 58 % of the KBP command area to be irrigated in the kharif season (see Table 7). Moreover, rice is the predominant crop in the kharif season cropping patterns, covering 41 % of the total area, even though, recent trends suggest that the area of rice, both in absolute number and also relative to other crops, has been decreasing from 20 % in 1970 to 15 % in 1997.

So, given these trends, under what conditions will the farmers in Bundelkhand region irrigate more paddy, or irrigate any other crop, in the kharif season? Did the decisions on proposed cropping patterns reflect the current trends on the ground or the farmer's preferences

Table 7. Trends of cropping patterns in the KBP command area districts.

	Overall cropping patterns[1] (%)				Irrigated cropping patterns[1] (%)			
Crops	1980	1990	1997	2006	1980	1990	1997	2006
Gross crop area (1,000 ha)	2,608	2,985	3,155	4.37	410	732	1,138	1.03
Kharif season								
Paddy	5.0	4.1	3.8	0.2	0.9	0.4	0.3	0.0
Jowar/	14.0	7.4	4.0	6.2	0.0	0.0	0.0	0.0
Maize	1.4	1.4	0.6	-	0.0	0.0	0.0	-
Pulses[2]	12.1	13.7	9.8	20.8[2]	0.0	0.0	0.0	0.0
Oilseeds[3]	3.1	9.2	14.1	22.7[3]	0.1	0.4	0.6	0.1
Vegetables	0.1	0.1	0.1	-	0.0	0.0	0.0	-
Fodder	-	-	-	-	-	-	-	-
Rabi season								
Wheat	35.9	33.5	35.8	32.8	65.5	66.6	61.5	69.1
Jorwar/Barley	2.5	1.1	1.0	0.3	10.6	2.8	2.0	0.1
Pulses[4]	22.8	25.3	26.2	16.4[4]	18.8	26.0	30.5	28.3
Oilseeds[5]	2.7	3.6	4.0	0.8[5]	0.5	1.2	2.7	2.4
Vegetables	0.3	0.4	0.3	-	2.1	1.8	0.9	-
Fodder	-	-	-	-	-	-	-	-
Sugarcane	0.2	0.2	0.3	-	1.4	0.7	0.7	-
Total	100	100	100	100	100	100	100	100

Notes: 1 –Source for estimates for 1980-1997 is tha secondary data collected by the ICRISAT, Hyderabad 2000, and for estimates for 2006 is the primary survey conducted by authors. Gross crop area of 2006 is the total area of the farms in the primary survey
2 - Kharif pulses include moong, urd and arhar
3 - Kharif oilseeds include soybean, sesame, and groundnuts
4 - Rabi pulses include peas, gram and masoor
5 - Rabi oilseed is mustard

in the command area? Certainly, the analysis of data shows that such decisions did neither. It is extremely important that these factors are taken into account when preparing the detailed project report. In fact, this is very critical in estimating the irrigation demand in the KBP. According to the feasibility report, the estimated irrigation water demand for June to October in the kharif season is nearly half of the total water releases from the Daudhan Reservoir to the project command area. What if the farmers decide not to irrigate their crops in the kharif season from the irrigation water releases? Under this scenario, can other major consumptive water-use sectors (domestic and industry) consume such a large quantity of water in the command area? These issues need to be addressed when preparing the detailed project report.

In the next section, we discuss in detail the benefits of irrigation on crop production and livestock as proposed by the feasibility report, and present alternative scenarios to assess how to increase the intended benefits.

Net Benefits of Irrigation Water Transfers

Ideally, the economic benefits of irrigation water supply include direct and indirect benefits on: 1) crop production; 2) animal husbandry; 3) farm equipments and input supplies (backward linkages); 4) agro-processing (forward linkages); and 5) employment generation. New irrigation transfers can have indirect positive impact in both inside and outside the project command area. The return flows of irrigation in the command area recharges groundwater. This in turn can facilitate conjunctive water use within the command area, and groundwater irrigation outside the command area. Therefore, the total ‘effective command area’ from the new irrigation supply includes both the total surface only and conjunctive irrigated area within the command, and the total area outside the command that groundwater (which is recharged from return flows within the command) irrigates.

New irrigation water transfers can also entail a benefit loss. This can be a gross benefit loss in the downstream of the reservoir due to the reduced river flow, and also in the upstream of the reservoir due to submergence of the crop area. Furthermore, such transfers can also create a benefit loss in the command area due to the acquisition of farm lands for the en route canal command.

We used the data collected from the primary survey for estimating the net economic benefits in three components. They are:

1. Value-added direct crop production and livestock benefits. The valued-added production is the total value of outputs minus total purchased inputs. The purchase inputs are the sum of the cost of crop production inputs, land rent, capital cost depreciation and hired and family labor costs. The value-added benefit from livestock production is the gross income from livestock production minus the total cost of inputs and labor.

2. Value-added indirect crop and livestock production in the non-command area irrigated through groundwater, which is recharged by the return flows of irrigation in the command area.

3. Crop and livestock production loss due to submergence of the crop area in the upstream of the reservoir.

We also estimated the following indirect economic benefits:

1. Value-added through forward linkages, which include the benefits due to agro-based industries, transportation and storage facilities, and employment generation.

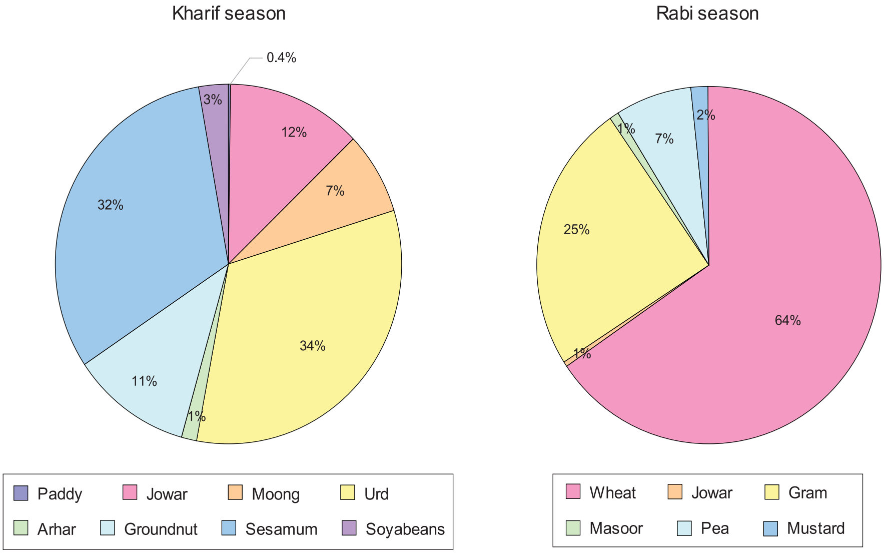
2. Value-added through backward linkages, which include the benefits due to increased farm supplies and services such as fertilizer, pesticide, farm equipment and employment generation.

However, information available from the primary survey on forward and backward linkages for ex ante benefit evaluation is very limited. Therefore, we used the multiplier factor, which captures the indirect benefits from irrigation in the command area due to increased forward and backward linkages in the region. Bhatia and Malik (2005) estimated that the irrigation multiplier for the Bakhra irrigation command in the Haryana, which assessed the indirect benefits of backward and forward linkage, is about 1.90 – which means every Rs. 100 that the project generates as a direct benefit will yield another Rs. 90 as an indirect benefit. Malik (2007) also argued that considering the small size of the command area and the level of diversification that can be expected with new irrigation, the KBP would not generate indirect economic benefits as much as those in the Bakhra irrigation command. He argues that the KBP can be compared with a small check dam in a village in the hill regions of Shivalik in Haryana. The World Bank (2006) has estimated the regional multiplier for the check dam in the Shivalik hills to be in the order of 1.40. Therefore, for this study, we used the regional multiplier of 1.4 to estimate the indirect benefits in the Bundelkhand regions due to transfers of irrigation water to the KBP. And we also assessed the sensitivity of the estimated irrigation benefits to higher regional multipliers.

Net Value of Crop Production in the Command Area

***Cropping Patterns*:** The results show that pulses and oilseeds dominate the cropping pattern of the kharif season (Figure 3). Interestingly, farmers in the KBP command area do not irrigate kharif crops regardless of whether they have access to irrigation or not (Table 8). In fact, major crops that are cultivated in this region, mainly pulses and oilseeds, do not require much irrigation, as rainfall meets most of their crop water requirement. Only one farmer who cultivated groundnuts in the groundwater command actually irrigated in the kharif season.

Figure 3. Annual cropping patterns in the KBP command area.

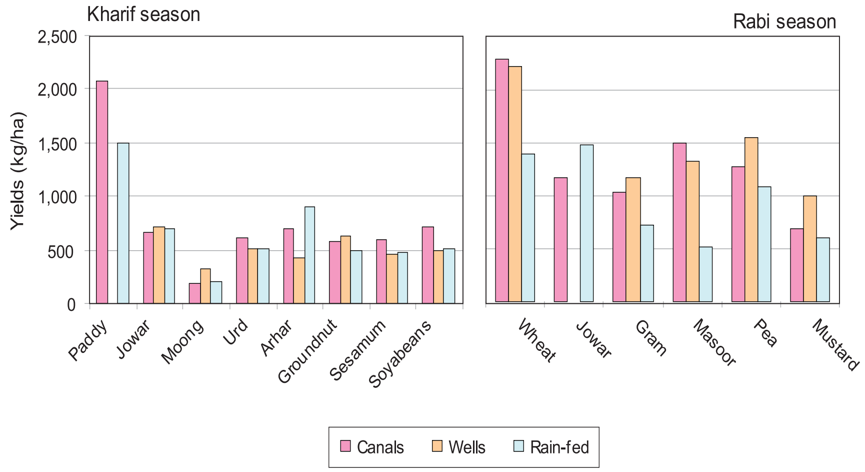


Source: Authors' estimates using the primary survey

Wheat and gram dominate the KBP's cropping pattern of the rabi season. Except for gram however, all other crops in the canal and well irrigated command areas are fully irrigated in the rabi season. Farmers who have access to irrigation, do irrigate only half of the gram crop area. Overall, only 45 % and 43 % of the annual crop area was irrigated in the existing canal and groundwater irrigation command areas. We used this cropping pattern to estimate the difference between the current net value of benefits of crop production in the KBP command area with and without irrigation.

Crop Yields: Except for paddy and *arhar*, there is no discernible pattern of difference in the crop yields of the kharif season between the three land use classes (Figure 4, see Annex Table 1 for details). Urd, seasume and groundnut, three of the major kharif crops, have slightly higher yields. *Jowar* and *moong* despite comprising a substantial area have lower yields in the canal command. However, none of these differences are statistically significant, mainly because no crops were irrigated in the kharif season in any of the command areas. The difference in yields of *arhar* and paddy in the irrigated and rain-fed areas cannot be established with sufficient accuracy due to low sample sizes. Of the 1,000 farmers in the sample, only 2 farmers cultivated paddy and 7 cultivated *arhar* in the whole command area.

Figure 4. Crop yields in canal, well and rain-fed commands.



Source: Authors' estimates using the primary survey

However, irrigation makes a big difference to crop yields in the rabi season. The yields of all crops in irrigated areas during the rabi season are significantly higher than those in unirrigated areas. The yields of wheat and gram, which are major rabi crops, in both canal and groundwater irrigated areas are about 60 % higher than those in unirrigated areas. There were only two farmers cultivating *jowar* in the canal command areas and five in the rain-fed areas. We assumed these differences in yields and net value of outputs to estimate the net value-added benefits of irrigation with the existing irrigation facilities.

***Net Value of Output of Crop Production*:** The net value of output of crop production is significantly higher in irrigated parcels than in unirrigated ones (Table 8). Within the canal command areas, no crops were irrigated in the kharif season. But the net value of output in the kharif season is highest in the canal command areas, followed by groundwater irrigated and rain-fed areas. This may be due to the fact that, although the farmers in the canal command do not irrigate their crops in the kharif season, they do mange their input application much better than the farmers in the rain-fed areas.

Table 8. Net value of outputs (NVO) per ha in canal and well irrigation and rain-fed command areas.

Season	Net value of output per ha of cropped area ($/ha)									
	Canal command area			Well command area			Rain-fed area	Total		
	I	UI	Total	I	UI	Total	Total	I	UI	Total
NVO-kharif	0	223	223	156	175	175	173	156	177	177
NVO-rabi	273	194	264	232	212	230	167	242	170	189
NVO-annual	273	219	244	231	179	202	170	241	174	183

Source: Authors' estimates based on primary survey

Notes: I- Irrigated; UI- Unirrigated

There were significant differences in the net value of outputs across the command areas in the rabi season. Almost all farmers in the canal and well irrigation commands do irrigate their crops in the rabi season. The net value of outputs of the rabi season crops in irrigated command areas is about 35 % higher than that of rain-fed crops. It is also interesting to note that unirrigated lands in the canal and groundwater command areas have a consistently higher net value of output than in the rain-fed lands.

Net Value of Livestock Production

Livestock Population: Livestock production, especially milk, is a major part of the agricultural economy in the Bundelkhand region. Of the surveyed area, 60 % of the households possess milking cows or buffaloes or goats (Table 9). This is rather high in comparison to the national data. More than 70 %s of the households in each command area have only a single milking animal, with groundwater irrigated areas have the highest percentage of single milking animal (81%). More farmers in the canal command areas keep milking cows (56 %), more so than those in groundwater (43 %) and rain-fed commands (48 %). More farmers in the groundwater irrigated (68 %) and rain-fed areas (62 %) keep milking buffaloes than those in the canal irrigated areas (50 %). These differences could be due to the nature of farm work and the requirement of animals for such activities and the availability of feed in the groundwater irrigated and rain-fed areas.

Table 9. Livestock rearing pattern in the Ken-Betwa project command.

Command area	Households with milking livestock	Pattern of livestock rearing (% of total milking livestock)							Milk productivity (liters/day/animal)		
	(%)	C	B	G	C+B	C+G	B+G	C+B+G	C	B	G
Canal	62	32	28	12	15	6	4	3	2.6	4.0	0.6
Well	56	25	50	6	16	2	2	0	2.4	3.8	0.6
Rain-fed	58	21	39	10	13	7	3	7	2.6	2.9	0.6

Source: Authors' estimates are based on primary survey

Notes: C- Cows, B-Buffaloes, G-Goats

Milk Productivity: Although the differences are not significant, the productivity of milking cows in the canal and rain-fed command areas is slightly higher than the well irrigated area. Cow milk, mainly produced for home consumption, provides a substantial part of the nutrition supply for the rural people. On the other hand, buffalo milk is a major source of income for the households. In general, buffalo milk has higher productivity than cow milk. The productivity of milking buffaloes in the canal and well command areas are significantly higher than the productivity in rain-fed areas. This is due to the fact that irrigated areas raise more cross-bred buffaloes than rain-fed areas, because higher fodder production in the irrigated areas better facilitate livestock rearing.

Livestock Feed**:** The main livestock feed in the KBP command area is dry fodder (mussel and wheat straw), green fodder (berseem, grass) *jowar* (chari, *jai* and *karvi*), and concentrates (pulses husk, *churi*/kapila, oilseed cake, wheat flour and balance cattle feed)—(Table 10). In general, when green fodder is available in plenty, farmers use more green fodder than dry fodder and concentrates for the feed, especially in the canal and groundwater command areas. Whereas, to compensate for the lack of green fodder in the rain-fed command areas, more concentrates are used in the feed given to milking animals. Thus, feeding cost per milking animal in the rain-fed areas is more expensive than in the canal irrigated areas.

Table 10. Feeding pattern for in-milk cows and buffaloes (kg/day/animal).

Command area	In-milk cow			In-milk buffalo		
	Dry Fodder	Green Fodder	Concentrates	Dry Fodder	Green Fodder	Concentrates
Canal	20.0	19.2	2.4	14.1	27.7	3.7
Groundwater	18.8	17.8	2.0	14.0	17.5	2.0
Rain-fed	19.0	9.4	4.0	13.0	9.2	4.1

Source: Authors' estimates are based on primary survey

Net value of Output of Milk Production**:** Due to higher fat content, the market price of buffalo milk is slightly higher than cow milk. But, due to the high cost of feeding of concentrates, the net value of output per milkng animal in the rain-fed area is low (Table 11).

With a substantially larger population of milking buffaloes and their higher productivity, groundwater irrigated area has a slightly higher net value of productivity per milking animal than in the rain-fed and canal commands.

Table 11. Household density, number of in-milk animals per household, net value of milk production per in-milk animal and net value of milk production per ha of net sown area.

Command area	Number of farming households/ha of net sown area	Number of livestock[1]/per household milking	Net value of output per milking animal	Net value of output/ha of net sown area
	Number	Number	$/animal	$/ha
Canal	252	2.37	715	264
Groundwater	316	2.00	790	280
Rain-fed	185	2.51	652	252
Total command	220	2.37	697	262

Source: Authors' estimates

Note: In-milk livestock includes cows, buffaloes and goats

In order to assess the benefits of irrigation, we estimate the net value of the output of milk production/ha of the net sown area in command areas. With new irrigation, the household density (# of households/ha of net sown area), percentage of households with milking animals, number of milking animals per household and the net value of production per milking animal will change. Our analysis shows that there are no substantial differences in the net value of livestock production/ha of the net sown area between the canal and rain-fed commands in the Bundelkhand region.

Direct Benefits from New Irrigation

Direct benefits of new irrigation supply is the sum of the net value added benefits from crop production and livestock, arising from changes in land use and cropping patterns. As discussed before, the feasibility study of the KBP proposes a rather different land-use and cropping pattern to that which exists at present (Table 2). It proposes to irrigate the whole crop area in the kharif season, whereas the survey data show farmers hardly irrigate any crop in the kharif season. It also allocates a significant part of the kharif season area to paddy crops, whereas the past trends show a decline in the paddy area. The survey results show that paddy covers only a very small area in the existing command areas of canal or groundwater irrigation. Given these temporal and spatial trends, it is likely that farmers in the KBP would continue to follow a similar land-use pattern to that which exists now. They would also diversify cropping patterns to include more non-paddy crops in the command areas, which have a greater demand and require little irrigation. In order to capture the implications of these different cropping patterns, we assessed the direct economic benefits and water demand under several scenarios. All scenarios assumed that the net sown area will remain a constant, while the gross crop area will increase from 460,000[1] ha up to 490,000 ha. The latter figure shows that the irrigation contribution to increase cropping intensity is very marginal. In fact, the NWDA (2006) has assumed in its feasibility study, that cropping intensity in the KBP project will increase only up to 134 %. We study the implications of these assumptions in the following scenarios.

Scenario 1. Scenario 1 (SC1) assumes a similar cropping pattern to that which exists now in the kharif season, but assumes the full irrigation of crops in the rabi season. The present cropping patterns show mainly pulses and oilseeds in the kharif season, and wheat and gram in the rabi season (Table 12). This scenario also assumes that the additional total crop area of 30,000 ha will be proportionately divided between crops.

Table 12. Cropping pattern (CP), irrigation pattern (irrigated [I] or unirrigated [UI] area) and net value of ha of crops.

Crops	Cropping pattern (CP)- as a % of total crop area, irrigation pattern (irrigated [I] or unirrigated [UI]) as a % of crop area							Net value per ha of crop area ($/ha)	
	Current patterns			Scenario 1		Scenario 2			
	CP	I	UI	CP	I	CP	I	I	UI
Kharif season									
Paddy	0.2	0	100	0.2	0	17.8	100	335	212
Jowar/bajra/maize	6	0	100	6	0	5.5	100	199	125
Pulses	21	0	100	21	0	8.7	100	357	225
Oilseeds	23	0	100	23	0	7.7	100	282	231
Vegetables	-	-	-	-		3.1	100	361	228
Fodder	-	-	-	-		0.5	100	260	164
Rabi season									
Wheat	33	49.6	50.4	33	100	35.1	100	247	144
Jowar/bajra/maize	0.3	5.5	94.5	0	100	0	100	199	125
Pulses	16	28.7	71.3	16	100	10.7	100	304	192
Oilseeds	1	67.4	32.6	1	100	6.5	100	271	222
Vegetables	-	-	-	-	-	1.4	100	361	228
Fodder	-	-	-	-	-	1.8	100	260	164
Annual crops									
Sugarcane	-	-	-			1.1	100	361	228
Total	100	22	78	78		100	100	260	192
Net value livestock production/ha of net sown area								269	252

Source: Authors' estimates

---

[1] Gross crop area in 2006 is estimated by multiplying the net sown area of 367,000 ha by the present cropping intensity of 122 %.

*Scenario 2***.** In scenario 2 (SC2) we assume the same cropping pattern as the one proposed by the feasibility study. In SC2, all crops are irrigated in the kharif and rabi season, and paddy and wheat are the predominant crops in the irrigation plans of both these seasons.

Scenario 3. Scenario 3 (SC3) has a similar cropping pattern to scenario 2 (SC2). However, it assumes a different irrigation plan, where farmers irrigate only paddy and vegetable crops in the kharif season. It is very likely that on average rainfall conditions, the other crops, mainly coarse cereals, pulses and oilseeds, do not require any irrigation in the kharif season. This scenario also assumes all 'rabi' crops receive full irrigation.

We assessed the net value of output of each cropping pattern using the estimated net values of irrigated and unirrigated crops from the primary survey. However, we also made the following assumptions in estimating the net value of output of all crops:

- The primary survey provided only the net value of output of the kharif crops that received no irrigation. Therefore, we assumed the differences of the net value of output per ha of all crops in the rabi season (US$260/ha with irrigation and US$164/ha without irrigation) between irrigated and rain-fed conditions and used these figures to estimate the net value of output of paddy, *jowar*, pulses and oilseeds under irrigation conditions in the kharif season. We multiplied the net value of these crops under un-irrigated conditions by a factor of 1.58 (=260/164-the ratio between net value per ha in irrigated to unirrigated area to estimate the net value under irrigated conditions.

- The primary survey did not capture the differences of net value of output of vegetables and sugarcane. Here too, we assessed the differences of net value of outputs of vegetables and sugarcane in irrigated and rain-fed conditions, by using the net values of output per ha of pulses and oilseeds in the kharif season. . The differences of net value in the output of all rabi crops is for the fodder crop.

- The indirect benefits of forward and backward linkages are estimated with the irrigation multiplier of 1.4.

The proposed scenario in SC2, with full irrigation, has the largest increase in the net value of crop production (Table 13). It increases 50 % over the current net value of crop production. However, the difference of net value between the proposed scenario in SC2 and other two scenarios is very insignificant. For example, the net value of crop production of SC2 is only 19 % and 7 % higher than SC1 and SC3, respectively. How do these benefits compare with the increase in irrigation?

A substantial part of the kharif crop area under SC1 and SC3 is not irrigated. Therefore, we estimated the total consumptive water use of crops, and used water productivity—net value of output per m^3 of consumptive water use—as a basis of comparison for performance between the scenarios (Table 13). The total net value added output in this table is the sum of the net value of production of crops and the livestock, and the indirect benefits of the additional irrigation water transfers of the KBP.

We noticed that the increase in consumptive water use in the KBP command area was comparatively higher than the value addition that irrigation created. This is evident from the difference in the current net value of production per m^3 of consumptive water use and the net values found in scenarios SC1 and SC2. For instance, the productivity per consumptive water use has, in fact, decreased from the present level of 0.16 $/$m^3$ to 0.13 $/$m^3$ in SC2. And the

Table 13. Net value of production, consumptive water use and the irrigation water requirements under different scenarios.

	Factors	2006	Scenario 1	Scenario 2	Scenario 3
1	Net sown area (1,000ha)	370	370	370	370
2	Gross cropped area (1,000ha)	460	490	490	490
3	Gross irrigated area (1,000ha)	140	260	490	387
4	Net value of crop production ($, million)	95	119	142	133
5	Net value of livestock production($,million)	96	96	100	98
6	Total net value of output ($, million)	190	216	242	231
7	Increase in direct benefits ($, million)		24	50	39
8	Increase in indirect benefits ($, million)		22	45	35
9	Total net value added benefits due to additional irrigation ($, million)		46	96	75
10	Total consumptive water use (million, m^3)	1,250	1,787	2,004	2,022
11	Net value of output per drop of consumptive water use ($/$m^3$)	0.16	0.14	0.15	0.13
12	Irrigation requirement (million m^3)	301	752	1,165	1,095
13	Change in irrigation requirement (million m^3)		450	863	794
14	Change in irrigation requirement - % of proposed irrigation supply (3,196 million m^3)		14	27	24

Source: Authors' estimates

productivity estimate, even at 1.9 regional multiplier level will increase only to 0.15$/$m^3$. Thus, given the prevailing differences of crop productivity of irrigated and rain-fed conditions, even the proposed cropping patterns will not significantly increase net benefits relative to the increase in consumptive water use.

Another significant fact to notice in the different scenarios is the differences in the net evaporative requirements. The additional crop irrigation requirement in SC2 is the highest, but it increases only by 867 million m^3, which is only 27 % of the proposed irrigation transfers. If the percolation requirement (of about 200 mm) is added to the paddy irrigated area, the additional irrigation requirement will increase by 1,220 million m^3, which is only 38 % of the total water transfers. This indeed is a very low figure compared to the envisaged irrigation transfers. It seems that the feasibility study has ignored the prevailing irrigation withdrawals or has taken a rather low irrigation efficiency when estimating the additional demand for irrigation.

We estimated the benefit-cost ratio of the irrigation component by assuming 10 years of the project construction period, US$431 million of the total cost as estimated by the NWDA, 100 years of the project's life span, and an average annual cost of 5 % of the total cost for operation and maintenance. At a 10 % discounted rate, the benefit-cost ratio of the irrigation component under the three scenarios is 0.4, 0.8 and 0.6, respectively. If the 1.9 multiplier is used for assessing the indirect benefits, the benefit-cost ratio increases to 0.5, 1.1 and 0.9, respectively for the three scenarios. Indeed, increase in the net benefits when compared to the cost of irrigation component of the KBP seems to be very insignificant, even under the most optimistic scenarios of the indirect benefits that the project would generate.

Conclusion and Policy Implications

This paper assessed the economic and other implications of the proposed cropping and irrigation patterns in the Ken-Betwa project. Our analysis shows that the proposed cropping and irrigation patterns do not match the changing face of cropping and irrigation patterns in this region. Although the feasibility study of the project proposes irrigation in the kharif season, neither the past trends nor the present cropping patterns suggest irrigation to be a determinant in agriculture during the kharif season in this region, in that the kharif season almost always receives adequate rainfall for meeting most of the irrigation requirements in this region. Moreover, the proposed irrigation pattern includes a substantial area under paddy in the kharif season. This is inconsistent with past trends, where the area under paddy has decreased by 10 % during 1980-1997, and is currently only 3.8 % of the total crop area. This clearly shows farmers' preference for paddy in the local area is waning, and the preference for other high-value but less water-intensive crops is increasing. So, then what economic benefits will the proposed irrigation patterns bring in?

Our analysis shows a marginal increase in the net benefits of the proposed irrigation patterns with respect to increased consumptive water use. The benefit-cost ratio of the irrigation component seems to be very small even under the most optimistic scenarios. We noticed that the incremental benefit of the net value of crop production in the KBP area is less than the increase in the crop consumptive water use. Moreover, according to our estimates, the additional requirement of irrigation for the proposed cropping pattern, even with full irrigation in the kharif season, is significantly lower than the proposed irrigation diversion from the Daudhan Reservoir to the command area. This situation gets even worse, if farmers decide not to irrigate in the kharif season.

No irrigation in the kharif season will have significant implications on the proposed irrigation releases to the command area. It is envisaged to release almost half of the annual allocation for irrigation (about 1,563 million m^3) to the KBP in the kharif season. If farmers would not use these releases, on the negative side, this water could create a flood situation in the low lying areas, waterlogging in the command area or vicinity of the canal and simply flow down to the river without being used beneficially in the command areas. As most of the rain in the Bundelkhand region falls in the kharif season, it is unlikely that the water transfers can have additional benefits in recharging the groundwater. In other words, this release is simply a loss to the system. As such, can the irrigation releases envisaged for the kharif season be stored in the reservoir for use in the rabi season? Perhaps a part of the releases can be. The gross storage capacity of the proposed reservoir at Daudhan is 2,775 Mm^3, which is significantly lower than the total 3,245 Mm^3 of water transfers envisaged to the KBP command area. In fact, the reservoir acts as a run-of–the river diversion structure for the purposes of water transfers through the en route command to the Betwa River. However, reservoir storage is more than adequate to store the full requirement of the rabi season water releases, which is estimated to be at 1,683 Mm^3. But the remaining water after the rabi season is concluded will have to be released before the start of the next season in order to capture the kharif season run-off.

Indeed our analysis also has certain limitations. We have not estimated the impact of water releases on the groundwater recharge, and the extent of area that is outside the command, but that can benefit from groundwater irrigation. This analysis has also not assessed the water surpluses of the Ken River to facilitate transfers to the Betwa River basin. Smakhtin et al. (2007), in another study that is related to the overall analyses of the river linking project, showed that the NWDA feasibility report has used annual time series data in estimating the dependable flow at reservoir sites. However, ignoring the monthly variations and using annual data will almost always result in higher dependable flows, which explain the perception that rivers indeed have surplus water for transferring to water-scarce basins. The assessment of benefit-cost ratio also has certain limitations. In the cost side, it did not consider the cost of rehabilitation and resettlement of displaced persons, cost of over-runs etc. These are some of the highly contentious issues of the discourse of the NRLP, in general, and the KBP, in particular. In the benefit side, the direct benefits of water use for hydropower and in the domestic and industrial sectors were also not considered. These would have generated significant benefits to the KBP region, as inadequate electricity and drinking water supply are major constraints for economic development in this region. In fact, we observed in our field studies, that in severe drought years, some farmers sell their livestock as they are unable to provide an adequate drinking water supply for their livestock, let alone fodder and other feed.

Nevertheless, our analysis suggests that during the detailed project report preparation phase, it is necessary to revisit and address the many concerns that perhaps the feasibility studies may have missed. They include:

- Evaluating the proposed cropping pattern with respect to the local socioeconomic requirements and agro-climatological conditions, and proposing a new cropping and irrigation plan that addresses these concerns and will also suit the present crop diversification trends so that these can be followed in the future.
- Selecting high-value crops that can increase the net value of crop production benefits at a rate higher than the increase in consumptive water use (or beneficial depletion). Reevaluating the irrigation water requirement for the proposed cropping patterns in different months, and assess the water surpluses that can be diverted from the Ken River to the Betwa River,
- Assessing the reservoir storage that is required to meet the water demand of the downstream of the Ken River, en route canal, and in the Betwa River basin,
- Assessing the potential for agricultural diversification with more livestock in the region, and their implications on the total water demand.

References

Alagh, Y.K. 2006. Methodology of Irrigation Planning. The Ken-Betwa Case. In *Interlinking of Rivers in India. Overview and Ken-betwa Link*, eds. respectively Yoginder K Alagh, Ganesh Pangare, and Biksham Gujja. New Delhi, India: Academic Foundation.

Alagh, Y.K.; Pangare, G.; Gujja. B. 2006. Interlinking of Rivers in India. Overview and Ken-betwa Link. New Delhi, India: Academic Foundation

Bharatndu, P.; Shaailendra, N.G.; Santosh, S.; Phourasia, L.P. 1998. Problems and Potentials of Bundelkhand with Special Reference to Water Resource Base. Uttar Pradesh: V.S.K (Banda) publications.

Bhatia, R.; Malik, R.P.S. 2005. Indirect Economic Impacts of Bhakra Multipurpose Dam, India. (Unpublished).

Chopra, K. 2006. The Feasibility Report of Ken-betwa Link Project: An Analysis of Assumptions and Methodology. . In *Interlinking of Rivers in India: Overview and Ken-betwa Link,* eds.Yoginder K Alagh, Ganesh Pangare, and Biksham Gujja. New Delhi, India: Academic Foundation.

ICRISAT (International Crop Research Institute for Sami Arid Tropics). 2000. Database for Indian Agricultural Statistics. Hyderabad, India: ICRISAT.

IWMI (International Water Management Institute. 1998. Climate and Water Atlas, Colombo, Sri Lanka: International Water Management Institute.

Malik, R.P.S. 2007. Assessing indirect impacts of new irrigation projects (personal communication).

Mohile, A.D. 2006. Facilitating Water Transfers- Preparing and Marketing of Water Transfer Reports. In *Interlinking of Rivers in India. Overview and Ken-betwa Link,* eds.Yoginder K Alagh, Ganesh Pangare, and Biksham Gujja. New Delhi, India: Academic Foundation.

NWDA (National Water Development Agency). 2005. Feasibility Report of Ken-Betwa Link. India: Ministry of Water Resources, Government of India.

Patkar, M.; Parekh, P. 2006. Critique of Ken-Betwa Feasibility Report: Resettlement, Rhabilitation, and Environmental Aspects: In *Interlinking of Rivers in India. Overview and Ken-betwa Link,* eds.Yoginder K Alagh, Ganesh Pangare, and Biksham Gujja. New Delhi, India: Academic Foundation.

Thakka, H.; Chaturvedi, B.C. 2006. Ken-Beta Link: Why it Won’t Click? In *Interlinking of Rivers in India. Overview and Ken-betwa Link,* eds.Yoginder K Alagh, Ganesh Pangare, and Biksham Gujja. New Delhi, India: Academic Foundation.

Annex Table 1. Sample survey results: The cropping and irrigation patterns and crop yields in the canal and groundwater command areas and the rain-fed areas.

Crop	Canal command area (Total sampled parcels = 320)					Groundwater (Total sampled parcels= 180)					Rain-fed (Total sampled parcels= 500)		
	Number of parcels	Crop pattern	Irrigated area % of total	Crop yield		Number of parcels	Cropping pattern	Irrigated area % of total	Crop yield		Number of parcels	Cropping pattern	Crop yield
				Irrigated	Un-irrigated				Irrigated	Un-irrigated			
	#	%	%	kg/ha	kg/ha	#	%	%	kg/ha	kg/ha	#	%	kg/ha
Kharif Season													
Paddy	1	0.4	0	-	2,083	-	-	-	-	-	1	0.1	1,500
Jowar	40	6	0	-	663	33	7	0.0	-	716	67	6	703
Moong	19	3	0	-	194	23	3	0.0	-	329	63	4	211
Urd	115	15	0	-	606	93	18	0.0	-	506	217	17	502
Arhar	4	1	0	-	699	4	1	0.0	-	432	3	0.3	897
Groundnut	46	5	0	-	586	30	6	2.5	1,300	622	94	6	500
Sesamum	110	15	0	-	598	66	15	0.0	-	459	203	16	475
Soyabeans	13	2	0	-	710	4	1	0.0	-	497	15	1	512
Rabi Season													
Wheat	221	35	99.5	2,305	1,988	130	31	98	2,275	1,104	346	32	1,393
Jowar	2	0.05	100	1,169	-	-	-	-	-	-	5	1	1,476
Gram	84	11	48	1,038	648	47	11	48	1,171	691	177	13	733
Masoor	2	0	100	1,496	-	1	0	100	1,333	-	4	1	525
Pea	20	3	100	1,278	-	33	6	92	1,580	1,210	38	3	1,092
Mustard	9	1.0	100	688	-	13	2	100	1,007	-	8	1	605
Annual total		100	45				100	43				100	

Source: Authors' estimates using the primary survey

Social Equity Impacts of Increased Water for Irrigation

Amrita Sharma[1], Samyuktha Varma[2] and Deepa Joshi[3]
[1] IWMI Tata Water Policy Program, Anand, India
[2] International Water Management Institute, Colombo, Sri Lanka
[3] International Water Management Institute, Regional Office, Hyderabad, India

Introduction

It is a commonly held belief that the benefits of irrigation are not limited to farming households, and that irrigation systems can make a significant contribution to reducing rural poverty in a region by creating employment and improving livelihoods (Chambers 1988). Economists often argue that irrigation's benefits will impact rural development gradually, where at first, income inequality may increase, but eventually an improvement is seen as the benefits trickle down and as economic multipliers gain momentum (Kuznet 1955 cited in Bhattarai et al. 2002). This paper unpacks some of the assumptions of the impacts of irrigation by taking a closer look at the beneficiaries of large irrigation investments. The basic premise of this research is that the population within command areas is not homogenous. By differentiating the population on the basis of landholding and social strata, a wide variety of outcomes can be observed. These irrigation-related impacts are often shaped by existing inequities within populations in terms of access to information, capital, land and the existing social stratification. This study looks at the Polavaram Project of Andhra Pradesh and studies it in comparison with the Nagarjunasagar Project (NSP) for an insight into the different factors that shape long-term poverty and the equity impacts of irrigation on command areas.

Methodology

As the Polavaram Project is still at a very early stage, two villages under the Nagarjunasagar command were chosen based on their similarities in hydro-geology and socioeconomic features with the proposed Polavaram command, to study irrigation outcomes (see Table 1 for socioeconomic profile of the villages). Given that more than 40 years have passed since the construction of the Nagarjunasagar Dam, its command offered a good opportunity to study the long-term (crystallized) impacts of irrigation on poverty and on altering social and economic situations. In total, 160 households were surveyed for the study, 40 from each village. An initial exploration revealed the land ownership status in the villages, and based on that, the sample was divided into four groups: 1) the landless; 2) those owning 0-3 acres; 3) those owning 3-10; and 4) those owning above 10 acres.

Table 1. Socioeconomic photo of the study villages.

	Nagarjuna Sagar Command		Proposed Polavaram Command	
Village name	Kondrepole	Velatoor	Chinnadoddigallu	Yernagudem
District	Nalgonda	Krishna	Vishakhapatnam	West Godavari
Mandal	Dameracharela	G.Konduru	Nakkapalle	Devarapalle
Population	6,000	5,800	7,000	7,837
Caste Distribution (%)				
Scheduled cast (SC)	24	35	10	21
Scheduled tribes (ST)	9	6	0	0
Backward class (BC) /Other Backward class (OBC)	55	38	34	28
General	12	21	47	51
Dominant caste	Reddis 150	Kapus 150	Kapus 600	Kamma 100
Land Distribution (%)				
Landless HHs	30	24	21	21
Upto 3 acres	42	19	39	44
3-10 acres	26	33	12	21
Over 10 acres	11	28	18	12
Average landholding	4	7	6	9
Source of Livelihood (%)				
% sample with farming as main occupation	56	38	49	67
% sample with farm wage labor as main occupation	29	44	39	31
Other water-dependent livelihoods	Livestock rearing	Livestock rearing	Livestock rearing	Livestock rearing
Migration	~ 20 % (seasonal, labor work, prevalent among SCs, BCs/OBCs only)	8	Very high - 41 % (seasonal, for agrl. or non-farm wage labor, prevalent among landless, young men)	2%
Paddy over (rough estimates)	2,207 acres- double crop	930 single crop	900 – single crop	2,500 – double crop
Cash crops (rough estimates)	-	2,780 mango	1,000 cashew	2,700– tobacco, sugarcane 1,000 palm oil 1,000
Land value	1/2-1 lakh	9-20 lakhs	5-16 lakhs	10 lakhs
Main mode for irrigation	Surface water (Head end village)	Surface water canal- fed tanks (Tail end village)	Largely tank irrigation or rain-fed farming	Groundwater
Groundwater level	Varies between 100- indeterminate as the canal flows	300 ft	250 ft. but only 1 inch pipe	300 ft.
Drinking water availability	Domestic water supply-piped/ hand pumps	Common water source	Common water source-severe water scarcity during peak summer months	Common water source

Study methods included in-depth village case studies, questionnaire surveys, and interviews with key informants, and focused on open ended discussions with different socioeconomic groups as well. The survey methods were used to generate a socioeconomic 'photo' of the villages, understand the water-livelihood linkages, and test certain popular hypotheses on inter-sectoral, inter-class and inter-caste equity issues. In addition, detailed case studies were used to capture the three main trends that were observed in the preliminary field visits: 1) the change in social geography of the command with increased land transactions and movements into (and out of) the region; 2) the long-term impacts of irrigation on livelihoods; and c) the gender disaggregated benefits of irrigation. Qualitative discussions also covered the issues of irrigation management and access to irrigation water, inclusion/ transparency of water management, crop productivity, livelihood security and diversity and perceived outcomes in terms of the nature of transformations as a result of irrigation. During the course of the study, continuous revisions were made to the tools and methods used, for example, initial plans to survey women farmers had to be changed as it became known that instances of women managing farms were rare. Over time, and with continued interactions with the community, thinking on the subject evolved—forcing adjustments to the approach.

Polavaram - Proposed Benefits and Concerns Expressed

The Polavaram Project is one of the eight projects that the current government of Andhra Pradesh plans to finish within its 5-year tenure, on an express basis. It has already launched a mega program named 'Jalayagnam', which plans to bring an additional 73 lakhs of acres of land under irrigation within a span of 5 years. However, the plans for Polavaram have been there for a long time, and the project derives its raison d'etre from several angles; only one of them stems from the reemphasis on agriculture and the need to provide cheap irrigation to boost the growth rate of agriculture. The project plans to irrigate 2.91 lakhs of hectares of land (1.29 along the right canal and 1.62 on the left). Apart from that, it proposes to stabilise existing *ayacuts*, supply water to the city of Vishakapatnam and for industry purposes, divert 80 TMC of water to the Krishna River basin, generate 720 MW of power and create navigable canals from Polavaram to Vishakapatnam (through a system of locks).

Interestingly, the project comes at a time when groundwater irrigation has become the norm in several parts of the state, faith in surface irrigation (canal and tank) is diminishing, and efforts at reviving them through more and more participatory irrigation management (PIM) reforms do not seem to be yielding the desired results. Reddy (2003) notes that huge expenditures incurred in irrigation development are not translating effectively into the area irrigated. On the other hand, in the absence of effective groundwater regulation, the dropping groundwater levels are also posing a serious threat to the future of irrigation in the state and these massive investments on irrigation infrastructure are reportedly also intended to reverse the groundwater drawdown and stabilise the irrigation scenario.

The biggest opposition comes to the project from the resettlement and rehabilitation (R&R) lobby. Currently, more than 276 villages are expected to be submerged under the project, mostly from the Andhra Pradesh region and few from Orissa and Madhya Pradesh.

There is considerable civil society mobilisation against the dam; many have started to name it the second ‘Narmada’. In Box 1, we mention all the concerns that are being raised against the project.

Box 1. Popular Oppositions to Polavaram

- The Rs. 9,000-crore project displaces 1.45 lakhs of people in AP, Chhattisgarh and Orissa and submerges several archaeological sites.
- The project seeks to irrigate the coastal districts of Visakhapatnam, Krishna, East and West Godavari and quench the thirst of Vizag city. The opponents advocate that the urban areas would be the biggest gainers and the dam is meant to boost industrialisation at the expense of agriculture and the livelihoods of several tribal communities.
- It also raises regional conflicts – main opposition is coming from Telangana (which has always felt left out), which questions the priority of irrigation investments in the state.
- Allegedly, villages that needed water desperately are left out, and areas which had good groundwater potential are included.

(*Source*: Newspaper articles and field visits 2006-2007)

At the village level, there is angst against the loss of land to canal construction. There has been considerable land loss due to canal construction, and the rates of compensation that the government is offering are well below the prevailing market rates. Though there was an increase in the rates offered after Polavaram was declared open, it was not much above the registration rates. The Polavaram left canal currently runs parallel to the one coming from Tadipudi Lift Irrigation Project and in some parts the two canals are as close as 400 m to each other. This doubles the area of displacement, estimated at 6,600 acres in total, as well as doubles the amount of resources required for the construction. If one takes into account canal displacement for both the left and right main canals of Polavaram, the land lost amounts to 6,523 acres[1] (Samata Report 2006). This loss of land to canal construction hits the small-scale and marginal farmers much harder as they lose their sole means of livelihood; the large-scale farmers, who are also adversely affected, are able to absorb the shock.

Testing Popular Hypotheses on Irrigation-Equity Links

Equity is an increasingly important concern for irrigation impact studies but has not been addressed sufficiently - “whether the benefits of irrigation have accrued to wider sections of society have not yet been answered adequately” (Bhattarai et al. 2002). Scholars such as Sampath (1990 cited by Bhattarai et al. 2002) find that surface-flow irrigation has produced greater inequality in the distribution of benefits across farms than lift irrigation, and more so in areas with skewed landholding.[1] These inequities jeopardize the poverty alleviation impacts of irrigation, and many authors believe that in order to maximize the benefits of irrigation development, it is important to have the right institutional environment and a ‘pro-poor’ focus while designing such large-scale interventions (ibid).

In this study we solely focus on those aspects of irrigation, which have a bearing on equity. Starting with the physical aspects, we first explore how the head and tail divide manifests itself, and how the inequities get sharper as a result of inefficiency in canal management, plus the iniquitous ownership of plots in terms of their location. Further, we go on to study the impact of canal irrigation on crop diversification. Finally, we study the irrigation-employment link to ascertain what irrigation brings to the resource-poor i.e., the landless and the marginal farmers, whose only tangible benefits from irrigation are increased labor opportunities. While the discussion is largely on findings from the NSP villages, Kondrepol and Velatoor, we also use data from Yernagudem and Chinnadoddigallu at certain places to add interesting dimensions to the discussion, such as the effects of different sources of irrigation –groundwater vs. canal vs. rain-fed tanks.

The Head-tail Divide

The discussion on the equity dimensions of irrigation projects is closely related to the unequal distribution of water across different reaches of canals. The head-end farmers and farmers in the middle reaches usurp a large share of the water through illegal lifting and diversions, leaving little or sometimes no water at all for the tail-end farmers. This is one of the major factors contributing to income inequality in irrigated agriculture and unfortunately, it continues to be one of the unresolved issues in water distribution policies in irrigation commands. The problem is particularly severe in large-scale irrigation commands with large numbers of smallholding farmers, which are found in the developing countries (Bhattarai et al. 2002). A study shows that within the different reaches of the Rohera irrigation command in India, and the Khadir irrigation command in Pakistan, the tail-end farmers received, on average, only about 20 % of the water that the head-end farmers of the respective irrigation commands received for winter wheat in 2000-01 (cited by Bhattarai et al. 2002). As a result of this, often there is a significant difference in the income levels of farmers in the different reaches of a canal. Chambers (1988) found that the income of head-reach farmers was more than six times higher than that of tail-reach farmers in a minor. Our investigation in the Nagarjunasagar command lends more evidence to such problems, and also brings other interesting dimensions to the unequal distribution of benefits like the impact of the politics involved in the location of plots.

---

[1] Due to highly skewed land distribution, large farms can obtain disproportionately large shares of incremental benefits from irrigation development—both in relative as well as in absolute terms. For example, small farms in India constitute about 46% of the total rural households, but they only get access to 15% of the total irrigable land and 14% of the total canal-irrigated area. However, larger farms (more than 4 ha), representing the top 12.5% of the households, get about 40% of the total canal-irrigated area and 38% of the total irrigated land (Sampath 1990; cited by Bhattarai, 2002). of the households, get about 40% of the total canal-irrigated area and 38% of the total irrigated land (Sampath 1990; cited by Bhattarai, 2002).

Unauthorized Water Withdrawal in Upper Reaches

The surveys in Kondrepole revealed that there was great dissatisfaction among the tail-end farmers with the distribution of water. The village received water from Vazirabad major, a major head with an original design of 410 cusec. The pressure on the major head however, had continuously increased with the rise in unauthorised water lifting and water diversions in the head and middle reaches. In view of the rising demand, the design was later increased to 513.97 cusec, but the problems of water distribution in the tail reaches continued. Now the requirement is proposed to be at 600 cusec and there is a significant push and pull operating between the different stakeholders. Reportedly, the tail-enders have appointed an unofficial water users association (WUA) to go to the major head and lift the sluice to ensure their share of water.

There is considerable angst against the authorities who have been quite lax on checking such diversions, especially since most of these diversions are, interestingly, justified by irrigation officials on humanitarian grounds. For example, apart from the unauthorized water lifting, majority of them created unauthorized *ayacut* in its upper reaches. This was estimated to be around 10,000 acres. During initial planning, several plots of land were not estimated to be in the *ayacut* because of elevation, rocks, etc. Over the years however, the farmers have labored to lower elevation, literally remove rocks and flatten hilly parts, and prepare the ground for irrigation. As a result, irrigation officials felt that the farmer's right to receive his due share of water for irrigation was a natural right. Along with these types of unauthorized *ayacuts*, lands under tanks were also irrigated under the NSP, again unofficially. We were told that when the NSP fills the tanks for drinking water and cattle, farmers under the tank-*ayacut* use the water for irrigation. No survey has been done to check such encroachments. On the contrary, the revenue authorities collect as water cess from these unauthorized *ayacutdars*.

Irrigation department officials, on the other hand, complain of unbridled democracy among farmers, and also the short staffing pattern (there has not been any recruitment in the staff since the last three decades). One official said, "Two decades ago, it was unheard of that an unauthorized drawing of water would go unchecked. Motors were seized, crops were allowed to dry up, and farmers were penalized." Today, the department is unwilling even to go on field inspections if they anticipate trouble. "We take detours, if we see tail-enders," they say.

The water users associations (WUAs) set up a decade ago, have yet to yield any results. There are 12 TC (territorial constituency) members to one WUA covering 4,000 acres. Farmers term the WUAs as non-starters. They say that the situation was better when there was no WUA, because the Irrigation Dept. officials were somewhat more accountable and would come for inspection, sort out problems etc. But, now officials insist that the WUA should handle issues of farmers with regards to conflicts in water distribution. During an interview, one person made a remark on the functioning of the WUAs as thus: "The WUA is also corrupt; it is active only when there is some money; after that, it is silent. In fact, the WUA is only active to ensure that their (own) areas do not have a tail end."

Location of Plots – Who is in the Head and Who is in the Tail?

In a study on the poverty dimensions of Irrigation Management Transfer in certain villages in Andhra Pradesh, Koppen et al. (2002) found that in the canal commands the small farmers invariably had their plots at the tail-end of the canal. Drawing from the literature available, we started with the hypotheses that the influential and better off farming households manage to have their plots in the upper reaches, while the lower castes and small-scale farmers get the more water deprived locations in the tail-end. Our analysis supports this argument to an extent. In our questionnaire we had asked people about the location of their plots with respect to the nearest distributary/ canal irrigation source. In Kondrepol, we found that most of the smallholders were concentrated in the tail-end, while in the upper reaches, the large-holders dominated (Table 2).

Table 2. Location of plots for different land classes in Kondrepol.

Kondrepol	Head	Middle	Tail
Average landholding	7	6	5
Smallholders	17	28	56
Medium-holders	15	31	54
Large-holders	73	18	9

Source: Analysis based on Primary survey 2006-07

In Velatoor too, we found a similar bias where the majority of the large-holders were concentrated in the head reach while the smallholders were pushed to the tail-end.

Table 3. Location of plots for different land classes in Velatoor.

Velatoor	Head reach	Middle	Tail end
Average landholding	7.91	5.58	5.58
Smallholders (till 3 acres)[2]	19	19	62
Medium-holders (3-10 acres)	44	8	48
Large-holders (above 10 acres)	50	30	20

Source: Analysis based on Primary survey 2006-07

---

[2] In the sample we found several Madigas and Malas having plots in the head reaches, contrary to our hypothesis. Further investigation revealed that these plots were too close to the head reach and that they faced frequent waterlogging. Thus, for the purpose of our analysis we have removed those plots from the sample.

Similarly, in terms of social groups, the tail region was again dominated by the BC/ OBCs/SCs (Table 3). In Kondrepol, the Gollas and Chakalis were concentrated in the tail reach while the head reach was dominated by the high caste or the general category population i.e., the Reddys and the Chowdarys. In Velatoor, the Kapus were concentrated in the tail reach along with the Gollas, while the Reddys had their plots in the upper reaches (Table 4). Interestingly, the data stands in contradiction to our hypothesis – the Madigas and Malas, belonging to the SC community had land in the upper reaches, especially in the case of the Velatoor village. Upon an in-depth investigation of this situation we found that most of these plots were too close to the head reach of the canals and, as such, often experienced problems of waterlogging.

Table 4. Location of plots for different castes in the Sagar command.

	Kondrepol				Velatoor			
Acharyulu					1 plot		middle	
Chakalis	2 plots			All tail	4 plots			All tail
Chowdary	4 plots		3 middle	1 tail				
Gollas	4 plots			All tail	13 plots	2 head	1 middle	10 tail
Goud	2 plots		middle		2 plots		1 middle	1 tail
Goundla					1 plot	head		
Kapus					9 plots	2 head		7 tail
Lambadi	4 plots	1 head	2 middle	1 tail				
Madigas	7 plots	3 head	4 middle		7 plots	head		
Mala	2 plots		1 middle	1 tail	10 plots	7 head	2 middle	1 tail
Marati					1 plot			tail
Mudi Raju	3 plots		1 middle	2 tail				
Potter	2 plots			2 tail				
Reddy	9 plots	5 heads	4 middle	1 tail	3 plots	head		
Uppara					3 plots	head	middle	tail
Vaddera	2 plots			2 tail				
Velama					2 plots	head		
Vishwa Brahmin					1 plot			tail

Source:Primary survey 2006-07

In the absence of regulatory support either from the irrigation authorities or the WUAs, the tail-enders have found their own mechanisms to ensure water availability. During interviews we found out that in Kondrepol they have organized themselves into an unofficial and illegal association, which employs two people at Rs. 3,000 a month to: a) check for obstructions all along the distributary, b) raise the sluices of the major, if and when necessary.. There have also been several direct protests by the tail-end farmers against the authorities; last year the Lambadas (an upwardly mobile community –for more on their transition see Paper 6) reportedly shaved their heads and sat in protest in front of the Nalgonda District Collectorate.

Box 2. The Arbitrariness of Irrigation Infrastructure

The conception and design of the distributaries, majors and minors themselves are riddled with controversies. Velatoor, one of the study villages, presents the case of arbitrariness of projects because of changes dictated by political compulsions.

According to the villagers, one of the local politicians in Velatoor having 300 acres wet land under tank irrigation has been able to get the route of the canal changed to suit his irrigation needs. The villagers say that with the earlier alignment, the canal would have passed south of the village, necessitating an uncertain lift to irrigate lands under the tank. However, the plan has now been changed and the canal would be passing through the north of the village, assuring water to the tank.

The other conflict is related to the Jakkampudi major, which despite being the last major in the tail end that passes through Velatoor does not get the 150 cusec it requires, because the canal is silted and water does not flow. Besides, upstream farmers from Vissanapeta, Gollapudi, etc, use water for paddy crop, not for the intended irrigated dry crops (crops which require only occasional wetting unlike intensive irrigation crop like paddy). Hence, the quantum of water coming down is much less. Velatoor villagers feel that this situation is entirely political, as the congressmen who own land in the upper reaches are politically powerful, and they influence the officials not to act to remedy this problem. Velavaleru, a village close to Velatoor, at a distance of 4 km, is the village of the local MLA. While Velatoor is known to be a village of laborers (as it is inhabited largely by Kapus and other laboring castes), Velavaleru is known to be a farmers' village, as Kammas are the dominant caste there; villagers loyal to the MLA also admit that the MLA got their village tank filled this year exercising influence. Farmers of Velatoor, largely Kapus, feel they do not have enough strength to stop these political influences, while Kammas in the upstream can easily influence changes in the canals and distributaries, major and minor.

Irrigation and Crop Diversification

One of the main impacts of irrigation is the increase in cropping intensity and crop diversification. In practice, it has been observed that high-valued and water-intensive crops, like sugarcane, are grown at the head-ends of the canal, and generate a higher yield and net return per hectare compared to other cereals (Bhattarai et al. 2002). This further aggravates income inequality across the different reaches of a canal system. In this section we explore whether there are conspicuous differences in the cropping pattern being followed across different farmer groups based on their landholding, caste, irrigation source and position in the canal system. Two villages-Velatoor and Yernagudem in the Polavaram command, which were surveyed for this study, clearly bring out the importance of the irrigation source in crop diversification. Both in Velatoor and Kondrepol, villagers confirmed that before the canal was commissioned they used to grow crops such as red gram, maize, *sajjar*, *jowar* and black grams, which are all rain-fed crops. With the commencement of canal irrigation however, there was a mass shift to paddy cultivation. Unfortunately, paddy cultivation has now become the norm in the region and in the entire Sagar command there is hardly any or little crop diversification to be seen.

Table 5. Cropping intensity and crop diversity across sample villages.

	Kondrepol	Velatoor	Chinnadoddigallu	Yernagudem
Area under single cropping	97	41	84	62
Paddy	100	70	54	24
Maize	-	30		
Cashew			38	
Sugarcane (Kharif)				26
Tobacco				46
Others (Grams,Sapota,Sarugudu,Tomato)			18	
Area under Annual Crops	-	59	16	23
Mango[3]	-	69	100	
Sugarcane	-	31		
Oil farms (Palm,Sesamum)				36
Coconuts				64
Area under Double Cropping	3			15
Kharif Paddy				50
Rabi Paddy				50

Source: Analysis based on primary survey, 2006-07, all figures are percentages

As Table 5 shows, the canal irrigated village of Kondrepol is the one with least amount of crop diversification. According to all the interviewed farmers the entire area is under paddy cultivation, and almost all of them (97 %) take a single crop a year, that too in the kharif season only. Canal irrigation seems to have become a demoting factor to diversification. Farmers in the region complain that there is nothing else they can grow except paddy as there is too much water. Further, as water is supplied at a low price it may be possible that there is little incentive for farmers to optimize its usage and grow high-value crops.

In the tail-end village of Velatoor, the respondents used tubewell irrigation to grow sugarcane. They also had a large area devoted to plantation crops such as mango, which are very much dependent on rainwater. The paddy grown in the area is irrigated through tanks, which are filled using canal water/rains. In Chinnadoddigallu, which is largely tank irrigated (tanks are filled using rainwater), a large share of the cultivated area was again, single cropped. Although only a very small share of the land was under mango (a dry crop) cultivation, crops were reasonably diversified - farmers in the region grew cashew (38 % of the single cropped area), sapota, red and black grams, tomato, sarugudu etc. Among the four sample villages, the most dynamic farming system was that of Yernagudem— a groundwater irrigated village. The respondents had 62 % of their cultivated land under single cropping, 23 % under annual crops and 15 % of the land was double cropped. Within the single cropped area, high-value crops

---

[3] In our sample, more than 40 % of the land cultivated was under mango cultivation, which does not require frequent irrigation and is termed as a dry crop.

such as tobacco (which occupied 46 % of the area) and sugarcane were more common. Only 24 % of the single cropped area was under paddy. Half of the paddy area was double cropped, thus increasing the net area under paddy cultivation.

In the Sagar command i.e. Kondrepol and Velatoor there was no significant difference in the cropping pattern across land classes or castes. Only in Velatoor, we found that there was a significant dependence of the SCs on mango farms. Many BC/OBC families also grew mangoes, but the instance of high caste farmers growing mangoes was rare. It was in the groundwater irrigated Yernagudem that we found some biases regarding the type of crops grown across different land classes. Tobacco, especially, was grown by the high caste and primarily by farmers having large landholdings - the average size of a landholding of a farmer growing tobacco was 15.4 acres. Sugarcane was grown by farmers of all castes and the average landholding of farmers growing sugarcane was 8 acres.

Irrigation and Employment Generation

From the equity perspective, knowing how much benefit the landless and the resource-poor are able to garner from such mammoth public investment, becomes extremely important. Increased rural employment as a result of higher cropping intensity, cultivation of labor-intensive crops plus opportunities for non-farm employment is the way that irrigation benefits reach the poor. However, it has often been found that such investments benefit the land-rich or ‘landed’ classes largely and the benefits to the resource-poor are not at all commensurate. In our study area, we found that while the ‘landed’ class was able to tap the opportunity and diversify to more remunerative livelihoods, in the absence of an effective wage regulation such benefits have remained largely elusive to the poor, and as a result the poor have failed to move out of the poverty trap (more on this in Paper 6). In this section we discuss our findings on the labor opportunities available to the landless and marginal farmers in the four villages —Velatoor (Sagar command[4]), Chinnadoddigallu (proposed Polavaram command and largely rain-fed/tank irrigated) and Yernagudem (groundwater irrigated).

In the Sagar command, the qualitative investigations revealed that initially when the canal water came in, there was a huge influx of labor from outside the region. Reportedly, out of the 300 landless households in Kondrepol, approximately 100 households are migrants from other places. This is one of the main reasons why the wage rates in the canal irrigated areas have remained suppressed. In Table 6 we see that the total number of labor days available for a landless or marginal farmer household in the tail-end village of Velatoor (using canal fed tanks) is 95 days for men and 96 days for women - there is a negligible instance of non-farm work. In the groundwater irrigated village of Yernagudem, we find that the number of work days on the farm is marginally higher than Velatoor for men and women both. However, if we include non-farm work available to laborers in Yernagudem, the divide becomes much sharper- laborers in Yernagudem have 37 more days of labor available to them. In Chinnadoddigallu, we found that since there was little wage labor opportunity available at home, a large number of laborers migrated to adjoining areas to work on sugarcane farms.

---

[4] We have excluded data from Kondrepol because of its poor quality.

Table 6. Total number of work days available (average).

	Canal-fed tanks irrigated Velatoor		Groundwater irrigated Yernagudem	
	Men	Women	Men	Women
Kharif Paddy	65	86	45	46
Rabi Paddy			43	56
Mango	36	33		
Sugarcane			88	100
				(Single respondent)
Farm work total	95	96	109	103
Non-farm work	60		83	
	(Single respondent)			
Average (farm and non-farm)	97	96	134	103

Source: Analysis based on Primary survey 2006-07

Table 7 gives the wage rates for men and women across three villages. The wage rates received by women are invariably lower than those of men. The difference is most pronounced in the case of Yernagudem. In the canal irrigated villages, while employment is more or less guaranteed, and often assured to mitigate labor migration, wage labor rates have not increased although landed received improved returns from irrigation. During a discussion, laborers in Kondrepole remarked, “All the money from the irrigation in Kondrepole goes out of Kondrepole – nothing stays here – especially as paddy prices fall steadily.” In the mostly well irrigated Kondrepole, wage labor is the lowest compared to other villages. A constant, although inadequate (lower than the national wage rate), income allows the landless poor to escape starvation and migration, but is certainly not a path out of poverty. Hanging the poorest by this kind of slender thread also encourages a stream of detrimental social impacts such as primarily alcoholism, and alcohol-induced impacts among men.

Table 7. Average wages paid to men and women laborers.

	Peak Wages		Wages Non-peak	
	Men	Women	Men	Women
Yernagudem	103	45	87	41
Chinnadoddigallu	70	0	62	39
Velatoor	75	36	63	37

Source: Primary survey 2006-07

Social Geography and Changing Livelihoods

A detailed look at the two villages of Kondrepol and Velatoor reveals how different communities in the villages have experienced significant changes in their material conditions, which can be attributed to the introduction of irrigation and its associated changes. This paper describes the movement of people into, out of, and around the villages of Kondrepol and Velatoor, and takes a social geographic perspective to examine how the NSP canal has affected different communities.

It has been observed that since the commencement of operations of the NSP and the flow of water through its canals, the social geography of the region had altered significantly. Changes in the location of different castes/communities in the area were driven by the route of the irrigation canal and the benefits it brought. Closely related to the examination of altering social geography in the villages is the changing and diversifying livelihoods that have taken place over the course of the years since the canal was built and its subsequent consequences. Communities have found that the canal has improved their opportunities to shift to different livelihoods, or add on more types of work to improve their security.

The Kondrepole village belongs to the Damaracharla Mandal, and is located in the Nalgonda District. It lies on the state highway from Hyderabad to Guntur. Fifty kilometers downstream of the Sagar Dam, at Vemanapalli, the highway itself crosses the Nagarasagar Canal. About 6 km upstream of Vemanapalli lies the Vazirabad major[5], which supplies water to Kondrepole that lies about 20.5 km from the major head as the canal water flows. Of the total 4,900 acres of land in the village, 2,207 acres are in the Nagarjunasagar Project's *ayacut* (area served by the dam) and 600 acres are forest lands, while the rest are mostly dry lands owned and distributed by the government. The dominant communities in the village are Madigas and Malas, both SC, Lambadas, (a nomadic tribe that has settled in the village), and Gouds (toddy tappers). There is also a large proportion of Gollas (Yadavas). Other castes include Kammari (blacksmiths), Kummaries (potters), and Chakali (washermen). Prior to the state delivery of irrigation water from the Nagarjunasagar, only a limited number of farmers had access to irrigation. Irrigation water was obtained from the tank in the village and through manual pumping of groundwater wells by using oxen. While paddy was grown in these areas, the predominant crops grown in the dry land were maize, *jowar*, castor and pulses. After nearly four decades of canal irrigation villagers have witnessed a major transition in their material condition.

Velatoor lies 1.5 km from the Jakkampudi major of the NSP left canal. The canal itself ends about 10 kms from Velatoor. Velatoor also lies about 10 km from the Polavaram Canal. Though the Krishna District is generally thought to be controlled by the Kammas (one of the most powerful and influential castes in Andhra Pradesh and leaders in agriculture), the Kapus, who are close rivals of the Kammas, account for about 150 households in Velatoor. While not having the same amount of land or extensive businesses as the Kammas, they have been an upwardly mobile and influential farming community (they both own land and also work as laborers). SCs, while being the majority caste in the village own approximately 550 households, 300 of which are Madigas

---

[5] All majors are named after tail-end villages. Vazirabad is the erstwhile taluqa village on the banks of the Krishna River.

and 250 Malas. Gollas or Yadavas account for 60 households and a small number of Reddis account for 10 households. Other communities are Goudas, Vaddera, Yanadi (ST), Kammaris, Vaisyas and others (in small numbers) belonging to artisan castes who now work as agricultural laborers. Of the 700 households in the village, there are about 250 landless households, while the rest own varied amounts of land - about 20 households own over 10 acres of land, but the majority (around 500 households) own between 3 and 10 acres.

Social Geography

Taking a closer look at the villages shows that certain communities with wide networks have been able to secure land with better access to the canal water, and have maximised the benefits of irrigation to work towards changing their livelihoods during the course of one or two generations. On the other hand, certain communities have slowly moved out or fallen into hardship as a result of losing their small land parcels to more enterprising and influential farmers. These movements and changes over time, since the introduction of irrigation, reveal how irrigation shapes the social geography of an area, giving important clues as to how existing inequities can benefit or be detrimental to communities positioned differently.

The Landed Move Out

The Lambadas of the Kondrepole village present an interesting example of how a community was able to capitalise on the benefits of irrigation. The case is of particular interest as it illustrates how the presence of a support system, network and protective legislation have collectively played a role in this community's ability to reap the benefits of irrigation and eventually move out.

While many of the Lambadas are migrants from elsewhere, the original Lambada inhabitants had land. The first Lambada educated engineer in Andhra Pradesh (AP) is from this village: his father owned 15 acres of land, all of which started to receive irrigation in 1969, the year the boy passed his engineering exam. In the wake of the precedent set by the boy's success in eventually obtaining a secure government job with various forms of support from the village, an example was set and other Lambada boys and girls have followed suit with similar aspirations.

One of the most important factors is the granting of ST status for Lambadas in 1977 in Andhra Pradesh (no other state in South India has given ST status to Lambadas and this may have contributed to their large population in the state). This has translated into the Lambadas cornering most of the reservations in education and employment for STs. The authentic tribes (forest tribes such as the Chenchus, Gonds, Koyas, Kondareddis, etc.) do not possess the networks in the towns and major villages that the Lambadas have, since they are largely confined to agency areas, whereas the Lambadas live out in the plains. While ST students do not pay tuition fees and almost always get scholarships, it is also true that the scholarships are not generous to cover all living expenses—books, travel costs, medical expenses, etc.—and are never given on time. The success of the Lambadas could not have been replicated in un-irrigated areas, in that the irrigation of Lambada lands has helped the next generation to sustain their education and other expenses. Farmers with assured irrigation are able to put aside cash to provide for their children's' schooling and college. Farmer Nenavath Chandru, for instance, is able to send Rs. 5,000 to his son in Delhi, who has completed his B. Tech and is preparing for his Civil Services exam, notwithstanding the fact that funding his education is a heavy financial drain on the family.

The Lambadas today boasts of 150-200 government employees, of which 100 are teachers, 20 engineers, 5 in the police service, 1 in the IAS, 1 in the Air Force, and one a revenue divisional officer. Of these employees, 20 are women. Four members of the community have migrated to the USA.

Networks and Political Capital

At the other end of the spectrum are the 'Coastal Kamma Farmers' who came virtually as marginal farmers, selling their less than one acre parcels in coastal Andhra, but with a specific knowledge of project locations. Today, they are among have the largest landholdings or are 'the big-landed' farmers of Kondrepol.

Box 3. The Kamma Community's Political Capital

Simhadri Subba Rao's father had half an acre of land in small village in Vishakapatnam mandal and was rated a marginal farmer. He sold his land 45 years ago, came to a village on the Mehboobnagar-Karnataka border under the Rajolibanda Project and purchased 5 acres of land. Subba Rao and his two elder sisters were born there. As there were poor roads and other facilities in that village and, the fact, that Subba Rao's father was not overly happy with the quality of the land, he came away with his family and bought 10 acres of land in the mandal neighbouring Damaraherla, where NSP waters were also going to be available. This was about 40 years ago. When asked about how Kamma families had managed to purchase land all over the state well in advance of projects, and before local people were aware themselves, he replied that the Kamma network working with politicians and bureaucrats had helped them to obtain such information.

Losing Land to the Canal

Kondrepole is a village with a large SC population. The SCs are the poorest people in the village, and since the introduction of irrigation there has been a variation among this group in terms of movement with their circumstances being largely dependent on land ownership. The Madiga community of the village were given as *inam,*[6] lands in return for *vetti* or unpaid work for the state. Interviewed respondents recalled times when Madiga elders would have to walk to Wadpalli everyday (14 km one way) to report to the Tahsildar (person responsible for revenue collection) there. On the Tahsildar's order they would be sent to different villages (where there were not sufficient SCs to do *vett*i) to perform duties such as collecting information reports from the government's agents and carrying instructions from the authorities in Wadpalli to the village officials. This work was done without any food or payment from anyone. Parangi Kanakaiah, an 80-year old man, recalls how often the Madigas did not have time to even earn

---

[6] Inam lands are lands given for work from the state.

their daily bread – they were always flying from one village to another on government work. When they could not feed their families, particularly if their wives/other earning members fell ill, they had to sell land to avoid prolonged starvation.

SCs lost land when the canal was being dug and immediately after water flowed into the canals (after a period of about 5 years since canal construction). The village itself has no records, and information gathered from the interviewed respondents show that the perception is that SCs have been forced to sell much of their land. Respondents clearly narrated that there was a Reddy farmer who had 40 acres under the tank, and the canal was dug for his benefit. Consequent to this, it was only the poor people who lost their land, and who however did not ask for compensation due to fear of reprisals. Respondents in Kondrepole reported that soon after canal waters started flowing, there was an influx of landless laborers in the region. As a result of this increase in labor supply, wages remained low, and irrigation did not improve their financial situation either. About 20-25 years ago, the Madigas too, lost considerable and valuable lands to the canal under the village tank, and they too were not given any compensation.

In Velatoor, at the tail-end of the Sagar canal, once again it was the poor who lost lands to the canal. Out of the 12 households who lost land and have not received compensation, 5-6 are SCs. Lands were also acquired for the canal in such a way that it rendered other lands uncultivable. For example, Manda Yesuda's 2 acres of land were cut into two uncultivable halves because of the canal, and in spite of losing an entire ½ acre to the canal under an acquisition that took place 7-8 years ago, he has yet to receive compensation With his land spilt into two fields, he finds that cultivation costs are doubled—neither a tractor nor laborers can cross over the two pieces of land.

Changing and Diversifying Livelihoods

Qualitative research on the communities in the study villages explored the question of how different communities fared after the coming in of irrigation and how well they have been able to make use of the economic opportunities presented to them. In the villages of Kondrepol and Velatoor, significant time has passed since the introduction of irrigation and it has served as a trigger of sorts for different communities to diversify and/or shift over to more or prosperous livelihoods depending on their situations. The examples of altering social geography come from Kondrepol and they also depict some of the circumstances under which people change their livelihoods. This section presents examples largely from Velatoor on some of the obstacles that communities face when they attempt to change their livelihoods.

It is interesting to note that when different groups were asked to rank the following assets in order of importance–land, water, finance, markets and physical ability to farm, different groups ranked them differently. Large-scale farmers ranked water and finance in the top two categories, medium farmers responded in the same way, while the small-scale farmers rated land, and then water. The landless put land in the top spot, and then said that capital was the next most important asset: "*The landed have several diversified activities—they trade in mangoes, they take the contracts for fish tanks, they take contracts for repairs to tanks and canals, they take a cut from all developmental activities in the village etc. We have nothing except our limbs. Only the landed get loans but we cannot because the banks ask for collateral as security,*" said landless farmer, Velatoor.

In cases where there are other options for livelihood diversification, other constraints appear to operate: "*We are living here for generations but not allowed to fish. Outsiders are given the lease to fish in the village tank, because they are from the Mudiraj community*[7]. *This is injustice. We do not have any society of our own. Some villages do not function like this. They allow local inhabitants also to take the lease [for fishing rights],*" said Parangi Robert, a Madiga from Kondrepol.

Such responses indicate that caste-based policies that attempt to protect some communities work to the disadvantage of others, especially in cases where there are limited opportunities.

Over the years, small farmers, predominantly among the Gollas and Kapus, have managed to move out of poverty. They have been able to retain their landholdings, and many have been able to educate their children to higher education and professional courses. The Gollas of Kondrepol continue with their sheep rearing, employ grazing hands from their own community as well as from other communities, and have built good houses. The Gollas who were interviewed narrated how they heard about the canal- they had first heard rumours of the canal construction, but were sceptical about it and the opportunities it promised. Some among them started to believe the rumours and promised benefits once a certain amount of construction had been completed, but others were not sure if the water flowing through the canals would be sufficient for irrigation. It was only after the first successful crop that they finally believed that they could be benefited.

Table 8. Who takes decisions related to farm and household matters? (As answered by male respondents).

	Men alone	Both	Remarks
Farm Decisions			
Decision on input purchase	✓		Women participation in these matters was seen only in the case of one woman farmer respondent
Decision on cropping pattern	✓		
Decision on irrigation management	✓		
Decision on sale of produce	✓		
Household decisions			
Decisions on education of children	60	40	The proposed Polavaram villages showed higher female participation vis-à-vis the Sagar command villages. Thus women's involvement seemed to be influenced more by other factors such as education and their social group
Decisions on marriage of children	35	65	

---

[7] Government allows lease of village tanks only to people of the Mudiraj community, a traditional fishing caste.

Gender

Women's participation in decision-making on farm issues was zero. One of the reasons for this could be that these questions were answered by men respondents only.[8] Table 8 presents the results of responses from them. We get to see a certain amount of participation from women in household matters, especially in the case of children's' marriage and education. What we found was that female participation was low in the Nagarjunasagar command villages namely, Kondrepol and Velatoor. On the contrary, Yernagudem had more women's participation. This could be attributed to the higher education levels in the village plus a larger proportion of the high-caste population.

Work Participation. In the proposed Polavaram command, close to 30 % of women in the age group of 13 and above, were found to be working on the farms as agricultural laborers. In this group, three women from the Chetty Balaji group introduced themselves as farmers. Twelve percent of the women were found to be pursuing their studies while the majority (50 %) were housewives.

Compared to the proposed Polavaram command, a higher percentage of women were engaged in work outside their houses in the Sagar command. Thirty-five percent of women were engaged as agricultural laborers. Ten percent of women in the age group 13 and above were pursuing their studies. A number of them were engaged in non-farm activities, working in the capacity of shop-keepers, washerwomen, craftswomen, teachers, and aanganwadi workers for example. Less than 30 % of women were housewives.

Savings and Loans. In the proposed Polavaram command, 30 % people said they saved money. Almost all of them saved in self help groups (SHG), few had accounts in banks. When we asked about loans, 86 % of the respondents said that they had taken loans, and half of these loans were for agriculture. The rest were consumptive loans for marriage, house expenditure etc. Sources for the loans were generally mixed – cooperative banks, the Andhra bank and local money lenders in different combinations. On the question of who decided to take the loan- the answer was commonly 'both' i.e., both men and women. The median amount of loan was 40,000 Indian rupees (INR).

In the Sagar command, 36 % of the respondents said that they saved money and that was with the SHGs. Eighty-eight percent of the people said that they had taken loans. Forty percent of these were for agricultural purposes and the rest for a host of other reasons such as health, marriage and general household expenses. The median amount of loan was INR 35,000.

---

[8] The questionnaire was originally intended to have been administered to both men and women members of the household but (because of lack of understanding on the part of the investigators) the question was addressed to men only.

Table 9. Time-use by men and women in the Nagarjunasagar command.

	Kondrepol		Velatoor		Sagar Command	
	Men	Women	Men	Women	Men	Women
Agricultural Work	6.83	7.08	6.68	7.44	6.74	7.23
Livestock	1.9	1.27	4.83	3	3.45	2.33
			(five samples)			
Domestic		3.51		4.01		3.66
Non-farm	5.88	3.43	7.7	4.8	6.73	4.0
				(four samples)		

Source: Authors' estimates based on survey

Table 10. Time-use by men and women in the Polavaram command.

	Chinnadoddigallu		Yernagudem		Proposed Polavaram	
	Men	Women	Men	Women	Men	Women
Agricultural Work	5.60	5.27	6.25	5.72	5.9	5.5
Livestock	2.06	2.05			2.06	2.05
Domestic	2.15	5.56	2.30	4.76	2.25	5.16
Non-farm	4.9		4.2		4.55	

Source: Authors' estimates based on survey

The time-use statistics provide interesting insights (Tables 9 and 10). We can see that in the Sagar command the average number of hours spent by men and women on agricultural work is higher than the Polavaram command. Further, the number of work hours of women on the farms is higher than that of men. In the proposed Polavaram villages however, the number of work hours on the farm is much less in comparison, and women's work hours are slightly lesser than those of men. In the Polavaram proposed command, women's time is spent more on household chores.

Concluding Remarks

The ownership of land remains one of the most critical pre-requisites to derive benefits from improved irrigation. Additionally, land size is also important in maximizing the impacts of improved production. This study reveals how richer, more powerful farming communities have been observed to move into new irrigation areas, buying out small pockets of scattered lands belonging to the poor. For these communities who are connected to influential networks, irrigation plans and designs are known in advance, leading to a significant amount of land trading and consolidation even before the water flows through the canals. For marginal landholders, on the other hand, the benefits from irrigation may help to cope with poverty, but does not necessarily provide an escape. In times of stress there is little option for these households but to sell their small parcels of productive land. In addition, canal construction usurps a significant amount of land from the cultivated commands. The inequity of a marginal farmer losing all or most of his land to the canal, and receiving poor or no compensation is incomparable to a large farmer losing a small piece of land. Yet, this very evident inequity is often given little thought in irrigation planning and design. Surface irrigation schemes, as commonly implemented, can suffer from several limitations that result from not taking into account these realities.

Another important issue that emerges is the lack of 'conscious design' in planning that attempts to target irrigation to the poorest geographical clusters. It is claimed that contour alone determines the path of irrigation canals – thereby self-selecting and excluding villages along their flows. However, analyses show this is not overtly true. Several discussions and studies of the irrigation maps of Andhra Pradesh show that at the macro level, irrigation plans have followed conscious political designs, and at micro levels, canal pathways are defined by elite interests and needs. This paper illustrates this point by showing the distribution of farmers along the canal and presents findings, which reveal that the majority of head-end farmers in irrigated villages are large-holding farmers belonging to dominant caste groups and have large amounts of land.

The impact on changing livelihoods is also revelatory. While certain enterprising and resourceful communities have been able to tap the economic opportunity thrown open to them by irrigation, the status of the landless and the SC communities has changed very little. An analysis of wage employment and wage labor in the 40-year old NSP system in Kondrepole shows that while employment is more or less assured to mitigate labor migration, wage rates have not increased – even though 'landed' farmers have secured improved interests from irrigation. A constant, although inadequate, income (lower than the national wage rate) allows the landless poor to escape starvation and migration, but does not offer a path out of poverty. Hanging the poorest by this slender thread also encourages a stream of detrimental social impacts – primarily alcoholism, and alcohol-induced impacts among men. Finally, irrigation interventions have made only a little dent on the unequal gender relationships. Four decades of reliable irrigation in Kondrepole have not brought change to women's access to and control over key primary assets – with little impact on their personal lives and decision-making.

While the largely sociological approach to the question in this study helps us characterize the post-irrigation scenario and the inequities therein, we, as the authors of this paper, believe that appreciating the fact that the impact of irrigation is not the same across different groups of people is the first step to formulating effective policies, which act as enablers to help communities avail the benefits of irrigation.

> *"The policy goal, in the case of an irrigation command, is to reduce this income inequality to a level accepted by society through appropriate institutional and policy changes in the irrigation system operation, and through improved maintenance and overall management of irrigation systems. This would help the poor and marginal sections of society to gain from the benefits of the windfall (irrigation infrastructure) provided by government."*
>
> - (Bhattarai et al. 2002).

Bhattarai et al. (2002) in their analysis on irrigation impacts on income inequality and poverty alleviation emphasize that the benefits coming from the introduction of new irrigation water could be multiplied by recognizing these inequities and making up for them by having the right institutional environment and a ‘pro-poor’ focus in policies. In order to engineer such policies, knowing who benefits, who loses and the processes by which this occurs, is the first step.

References

Bhattarai, M.; Sakthivadivel, R.; Hussain, I. 2002. *Irrigation Impacts on income inequality and poverty alleviation: Policy issues and options for improved management of irrigation systems*. Working Paper 39. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Chambers, R. 1988. *Managing canal irrigation: Practical analysis from South Asia*. New Delhi, India: Oxford & IBH Publishing Co. Pvt. Ltd.

Osskarsson P. 2005. *Polavaram Multi-Purpose Project,* A report prepared for SAMATA, Hyderabad, Andhra Pradesh Websites referred:
http://www.jalayagnam.com/
http://www.blonnet.com/2005/05/19/stories/2005051903271700.htm
http://www.esgindia.org/moefsuno2005/Polavaram %20Dam%20Andhra%20Pradesh.doc

Converting Rain into Grain: Opportunities for Realizing the Potential of Rain-fed Agriculture in India

Bharat R. Sharma[1]*, K.V. Rao*[2]*, K.P.R. Vittal*[2] *and Upali A. Amarasinghe*[1]
[1]*International Water Management Institute, Asia Regional Office, New Delhi, India*
[2] *Central Research Institute for Dryland Agriculture, Hyderabad, India*

Introduction

Rain-fed agriculture is practiced on 80 % of the world's agricultural land area, and generates 65-70 % of the world's staple foods, but it also produces most of the food for the poor communities in developing countries and least favored areas. The low and variable productivity of these lands is the major cause of poverty for 70 % of the world's poor inhabiting these lands. The largest challenges of poverty-related undernutrition are found in arid, semi-arid and dry-humid, rain-fed regions of the developing countries (Falkenmark and Rockstrom 1993). The distinct feature of rain-fed agriculture in these developing countries is that both productivity improvement and expansion has been slower relative to irrigated agriculture (Rosegrant et. al. 2002). But, as Pretty and Hine (2001) suggest, there is a 100 % yield increase potential in rain-fed agriculture in the developing countries, compared to only 10 % for irrigated crops. This calls for increased efforts to upgrade rain-fed systems globally and, especially in developing countries to provide sufficient and affordable food and nutrition to the vast populations.

India ranks first among the rain-fed agricultural countries of the world in terms of both extent (86 M ha) and value of produce. Due to little alternative opportunities available outside the agricultural sector, the high population of landless households and agricultural laborers, and low land and labor productivity, most of the poverty is concentrated in rain-fed regions (Singh 2001). At the same time, there is growing evidence to suggest that agriculture continues to play a key role in economic development and poverty reduction in these regions ((World Bank 2005; Irez and Roe 2000). Some of the available estimates suggest that 1 % increase in agricultural productivity translates to 0.6 –1.2 % decline in the percentage of rural poor (Thirtle et al. 2002). The only silver lining in the scenario is that there appears to exist a significant potential for raising productivity in rain-fed systems. Yield gap analyses, undertaken by the Comprehensive Assessment, for major rain-fed crops found farmers' yield to be a factor of 2-4 times lower than the achievable yields and offering substantive opportunities for realizing the potential of rain-fed agriculture (Molden 2007).

Rain-fed Agriculture Scenario in India

Rain-fed areas in India are highly diverse, ranging from resource-rich areas with good agricultural potential to resource-constrained areas with much more constrained potential. It is in the rain-fed regions where cultivation of nutritious (coarse) cereals (91 %), pulses (91 %), oilseeds (80 %) and cotton (65 %) predominates. Rosegrant et al. (2002) employing the IMPACT model have estimated that even by 2025, one-third of India's cereal production shall be contributed by rain-fed areas (Table 1). Rain-fed agriculture supports 40 % of India's population. Earlier, the rain-fed farming systems, because of its risky nature, were dependent upon locally available inputs and grew traditional drought-resistant crops. But over-time cropping systems have changed (Kanwar 2001), and farmers have started cultivating high-value (but vulnerable) crops requiring intensive use of costly inputs.

Table 1. Rain-fed and irrigated cereal area, yield and production in 1995 (actual) and 2025 (computed), and fraction of rain-fed area and production for India.

Parameters		1995 (actual)	2025 (computed with IMPACT model)
Irrigated	Area, M ha	37.8	46.7
	Yield, t/ha	2.65	3.81
	Production, M tonnes	100.3	177.7
Rain-fed	Area, M ha	62.3	49.8
	Yield, t/ha	1.20	1.63
	Production, M tonnes	74.6	81.4
Rain-fed area, %		62.2	51.6
Rain-fed production, %		42.7	31.4

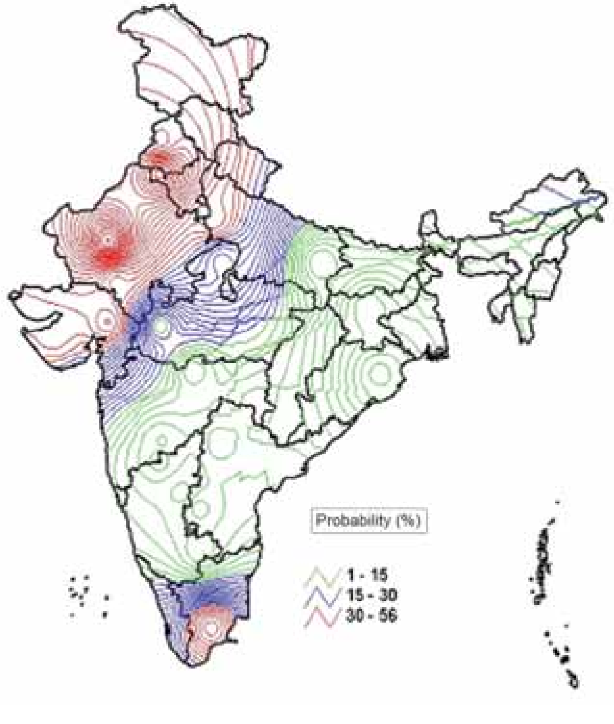
Source: Adapted from Rosegrant et al. (2002).

The last 4 decades of Indian agriculture, which registered overall impressive gains in food production, food security and rural poverty reduction in better-endowed 'Green Revolution' areas, by-passed the less-favored rain-fed areas, which were not partners in this process of agricultural transformation. Particularly, the last decade has witnessed serious distress among the more enterprising small and marginal farmers in the rain-fed regions who opted to replace, with little success, traditional low-value crops with high-value (but more vulnerable) and input-intensive crops through borrowed resources. As an extreme desperate step, over 25,000 farmers, mainly from rain-fed regions, committed suicide during the past 9 years—every 8 hours a farmer took his life (Lobo 2007). Besides several other factors related to agriculture sector as a whole, e.g., adverse meteorological conditions resulting in long dry spells and droughts, unseasonal rains and extended moisture-stress periods with no mechanisms of storing and conserving the surplus rain to tide over the scarcity/deficit periods, were the major causes for non-remunerative yields and heightened distress. It is only recently that the Government of India has constituted a National Rain-fed Area Authority (2006) to address these issues and develop and implement a comprehensive single-window program for the development of rain-fed areas in the country.

Constraints of Rain-fed Agriculture

Rainfall is a truly random factor in the rain-fed production system, and its variation and uncertainty is high in areas of low rainfall. Semi-arid regions, however, may receive enough annual rainfall to support crops but it is distributed so unevenly in time and/ or space that rain-fed agriculture becomes unviable (Reij et al. 1988). Rockstrom and Falkenmark (2000) note that due to high rainfall variation in semi-arid regions, a decrease of one standard deviation from the mean annual rainfall often leads to the complete loss of a crop. Whereas in the arid zones (< 300 mm/annum) absolute water scarcity constitutes the major limiting factor in agriculture; in the semi-arid and dry sub-humid tropical regions managing extreme rainfall variability in time and space is the greatest water challenge. Dry spells, which generally are 2-4 weeks of no rainfall during critical growth stages causing partial or complete crop failures, often occur in every cropping season. The probability of deficient rainfall (deficiency in rainfall numerically equal to or greater than 25% of the normal) in India during the southwest monsoon period is: once in 2.5 years in West Rajasthan; once in 3 years in Gujarat, east Rajasthan, western Uttar Pradesh, Tamil Nadu, Jammu and Kash-mir, Rayalaseema and Telangana; once in 4 years in the south interior Karnataka, eastern Uttar Pradesh and Vidarbha; once in 5 years in West Bengal, Madhya Pradesh, Chattisgarh, Konkan, Coastal Andhra Pradesh, Bihar, Jharkhand and Orissa; and once in 15 years in Assam (very rare) and Kerala. Even dry sub-humid regions, where rainfall varies between 750-1,200 mm, experience contingent drought

Figure 1. Probability of occurrence of terminal droughts in India—consecutive 3 dry weeks from second week of September.



situations due to a break in monsoon conditions. Based on its time of occurrence, such rainless periods/ agricultural drought may be termed as early season drought, mid-season drought and terminal drought. While early season drought can be mitigated through replacement with short-duration varieties or change in the cropping pattern, droughts at the latter two stages have potential to cause serious damages to crop production (Figure1). Terminal droughts are more critical as the final grain yield is strongly related to water availability during the reproductive stage. Apart from these short-duration droughts (dry spells), in the low to medium rainfall regions, the rainfall amount and distribution may be sufficient to raise only a low water requiring hardy crop but not a sensitive crop with high water requirements. Introduction of such a crop for economic reasons leads to the early appearance of drought conditions and crop failures.

Though water deficiency at critical crop growth stages is the major constraint of rain-fed agriculture, water itself may not always be the primary limiting factor for food production even on the so-called 'drylands'. Analysis of farmers' participatory field trials in more than 300 villages, showed that the existing practices of rain-fed agriculture has depleted soils not only in organic matter and macro-nutrients but also in micro- and secondary nutrients, and substantial gains (70 to 120%) are observed when crops were supplied with adequate quantities of these nutrients (Wani et al. 2005; Rego et al. 2005).

Effect of Irrigation Intensity on Crop Yields

Most research studies on the impact of irrigation on crop yields are conducted under high input use and on small plots, and thus fail to capture the scale impacts at district/ regional level and depict a high effect of irrigation. But, under actual farming conditions in developing countries like India, the exogenously supplied inputs show a great deal of spatial variation and impact the overall gains at the district/ regional level. An exercise based on district level secondary statistics to assess the effect of 'irrigation' and 'no irrigation' for the various crops in the 16 major states of India (where the rainfall is less than 1,500 mm/annum) revealed that:

i. productivity increase due to irrigation varies between 7-74 %, except for soybeans (0 %) and rabi rice (550 %);

ii. achievable yields are much higher than productivity levels achieved through irrigation and improved practices at the district level;

iii. productivity enhancement due to irrigation is less than 30 % among oilseed crops, except for castor (52 %) and sunflower (47 %); and

iv. among cereals, millets (pearl millet and finger millet), maize and barley recorded less than 30 % increase in productivity due to irrigation.

Yield differences between irrigated and rain-fed areas are more pronounced when the crop is grown under a variety of agro-ecological regions, compared to its concentration in few and similar districts. Though the effect of irrigation on crop yields suggest low gains for few crops, on-farm trials and evaluation reports of watershed projects (Joshi et al. 2004; Sastry et al. 2004) suggest that the effect of supplementary irrigation on rain-fed crop yields is considerably higher (Table 2). Therefore, an assessment was made to identify opportunities for water harvesting and supplemental irrigation to overcome dry spells during mid/ terminal droughts so as to stabilize the production.

Table 2. Effect of supplementary irrigation on the yield of rain-fed crops at different locations in India.

Location	Crop	Yield, t/ha Without irrigation	Yield, t/ha With critical irrigation	% increase with supplementary irrigation (Ratio of irrigated versus rain-fed yield)
Ludhiana (4)*	Wheat	1.92	4.11	114.06 (2.14)
Rewa (4)	Wheat	0.57	1.88	229.82 (3.30)
Varanasi (2)	Barley	2.60	3.36	29.23 (1.29)
Bijapur (5)	Sorghum	1.65	2.36	43.03 (1.43)
Bellary (4)	Sorghum	0.43	1.37	218.60 (3.19)
Rewa (4)	Upland rice	1.62	2.78	71.60 (1.72)

Source: Reports of All India Coordinated Research Project on Dryland Agriculture, Hyderabad

Note: * Figures in parenthesis indicate average number of seasons

Supplemental Irrigation through Rainwater Harvesting

Supplemental irrigation is a key strategy, so far under utilized, to unlock rain-fed yield potentials. The objective of supplemental irrigation is not to provide stress-free conditions through the crop growth for maximum yields, but to provide just enough water to tide over moisture scarcity at critical growth stages to produce optimal yields per unit of water (Oweiss et al. 1999; Sharma and Smakhtin 2004). The existing evidence indicates that supplemental irrigation ranging from 50-200 mm/ season (50-200 m^3/ha) is sufficient to mediate yield-reducing dry spells in most years and rain-fed systems, and thereby stabilize and optimize yield levels. Agarwal (2000) suggested that India should not have to suffer from droughts, if local water balances were managed better. Collecting small amounts using limited macro-catchments water harvesting, local springs, shallow groundwater tables or most importantly conventional water harvesting during rainy season can achieve this. The assessment presented in this study presents the estimation of available (surplus) rainfall runoff during August (second fortnight)/ September that is required mainly to mitigate the terminal drought. The study identified the dominant rain-fed districts for different crops (contributing up to 85 % of total rain-fed production), made an assessment of the surplus/ runoff available for water harvesting and supplementary irrigation in the identified districts, estimated the regional water use efficiency and effect of supplemental irrigation on increasing production of different crops and, finally, a preliminary estimate of the economics of water harvesting for supplemental irrigation in rain-fed areas.

Identification of Dominant Rain-fed Districts

To make an improvement over the existing criterion of the ‘fixed’ or ‘variable’ percentage of the irrigated area in the district, all the districts in the descending order of area coverage (for a given crop) limited to a cumulative 85 % of total rain-fed area for each crop in the country, were identified and termed as ‘dominant rain-fed districts’ (for a given crop). The crops covered are sunflower, soybeans, rapeseed mustard, groundnut, castor, cotton, sorghum, pearl millet, maize, pigeon peas and rice (in kharif), and linseed and chickpeas (in rabi). Thus an area of 39 M ha was accounted under selected crops. This helped in the identification of the major region for a crop, in that although all the crops are grown in most of the districts, there are a few crops that have specific agro-climatic requirements. Details on dominant rain-fed districts for various crops are given in Table 3. Development activities related to a specific rain-fed crop should be taken up first in these identified districts and secure a major impact on productivity.

Table 3. Total and ‘dominant districts’ for the important rain-fed crops in India.

Crop	No. of districts in		
	Rain-fed states	AESR*3-13	Districts covering cumulative 85 % of rain-fed area (dominant districts)
Sunflower	224	179	11
Soybean	202	160	21
Rapeseed mustard	265	214	29
Groundnut	316	243	50
Castor	202	157	12
Cotton	296	237	30
Sorghum	346	261	71
Pearl millet	346	261	43
Maize	346	261	67
Pigeon pea	266	215	83
Chickpea	346	261	85

Source: Authors’ estimates

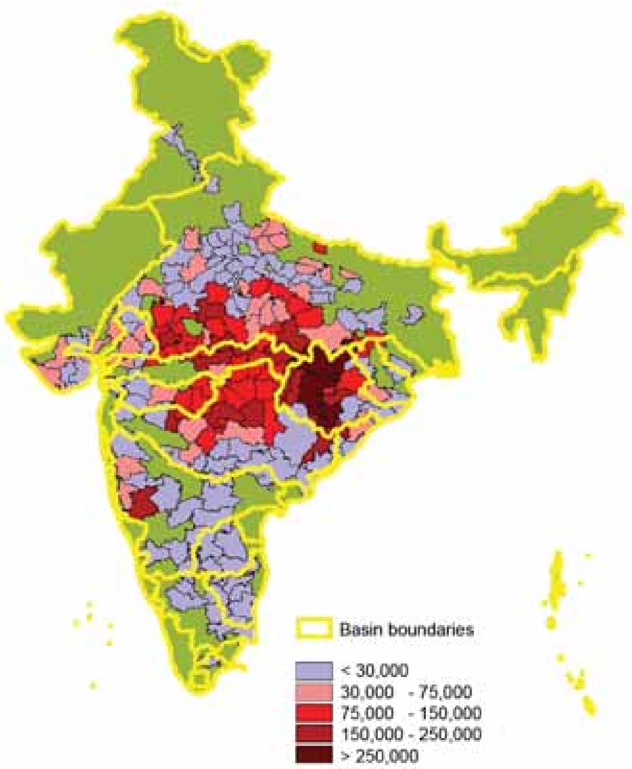
Notes: * Agro-Ecological Sub regions as defined by NBSSLUP, Nagpur

Assessment of Available Surplus/ Runoff for Water Harvesting and Supplemental Irrigation

Total rainfall in India is spread over few rainy days and fewer rain events (about 100 hours in the season) with high intensity, resulting in large surface runoff and erosion and temporary stagnation. In either of the cases this ‘green water’ is not available for plant growth, and has very low productivity. Local harvesting of a small part of this water and utilizing the same for supplementary/ protective irrigation to mitigate the impacts of devastating dry spells, offer a good opportunity for increasing productivity in the fragile rain-fed systems (Rockstrom et al. 2001; Sharma et al. 2005; Wani et al. 2003). For a national/ regional level planning on supplementary irrigation, one needs to make an assessment of the total and available surplus runoff, and the potential for its gainful utilization. In the present study, both crop season-wise and annual water balance analyses were done for each of the selected crops cultivated in the identified districts. Whereas, the annual water balance analysis assessed the surplus and/or deficit during the year to estimate the water availability and losses through evaporation; the seasonal crop water balance assessed changes in temporal availability of rainfall and plant water requirements. The water requirement satisfaction index was used for assessing the sufficiency of rainfall vis-à-vis the crop water requirements.

The total surplus from a district is obtained by multiplication of seasonal surplus with the rain-fed area under the given crop (Ferguson 1996). The total surplus available from a cropped region is obtained by adding the surplus from the individual dominant districts identified for each crop. An estimated amount of 11.5 M ha-m runoff is generated through 39 M ha of the prioritized rain-fed area. Out of the surplus of 11.5 M ha-m, 4.1 M ha-m is generated by about 6.5 M ha of rain-fed rice alone. Another 1.32 and 1.30 M ha-m of runoff is generated from soybeans (2.8 M ha) and chickpea (3.35 M ha), respectively. Total rain-fed coarse cereals (10.7 M ha) generate about 2.1M ha-m of runoff. Spatial distribution of runoff on agro ecological sub- region and river basin-wise is shown in Figure 2. Based on the experiences from watershed management research and large-scale development efforts, practical harvesting of runoff is possible only when the harvestable amount is larger than 50 mm or greater than 10 % of the seasonal rainfall (CRIDA 2001). Therefore, surplus runoff generating areas/ districts were identified after deleting the districts with seasonal surplus of less than or equal to 50 mm of surplus, and those districts generating runoff of less than 10 % of seasonal rainfall. Table 4 shows the summary of surplus and deficit for various crops after deletion of districts,

Figure 2. Spatial distribution of surplus runoff (ha-m) across dominant rain-fed districts and river basins of India.



Source: Authors' estimates

Table 4. Potentially harvestable surplus runoff available for supplemental irrigation under different rain-fed crops of India.

Crop group	Crop	Rain-fed crop area ('000 ha)	Surplus (ha-m)	Deficit (ha-m)
Cereals	Rice	6,329	4,121,851	0
Coarse cereals	Finger millet	303	153,852	0
	Maize	2,443	771,890	0
	Pearl millet	1,818	359,991	0
	Sorghum	2,938	771,660	0
Total (Coarse cereals)		7,502	2,057,393	0
Fiber	Cotton	3,177	757,575	8,848
Oilseeds	Castor	28	14,489	0
	Groundnut	1,663	342,673	1,646
	Linseed	590	306,360	0
	Sesame	1,052	416,638	0
	Soybeans	2,843	1,329,251	0
	Sunflower	98	11,811	0
Total (Oilseeds)		6,274	2,421,222	1,646
Pulses	Chickpea	3,006	1,304,682	9,166
	Green gram	458	80,135	0
	Pigeon pea	1,823	659,328	238
Total (Pulses)		5,287	2,044,145	9,404
Grand total		28,569	11,402,186	19,898

Source: Authors' estimates

which generate less than the utilizable amount of runoff. This constitutes about 10.5 M ha of rain-fed area, which generates seasonal runoff of less than 50 mm (10.25 M ha) or less than 10 % of the seasonal rainfall (0.25 M ha). Thus the total estimated runoff surplus for various rain-fed crops is about 11.4 M ha-m (114.02 billion cubic meters, BCM) from about 28.6 M ha that could be considered for water harvesting. Among individual crops, rain-fed rice contributes a higher surplus followed by soybeans. Deficit of rainfall for meeting crop water requirements is also visible for crops like groundnut, cotton, chickpeas and pigeon pea.

Based on this available surplus, the irrigable area was estimated for a single supplemental irrigation of 100 mm (including conveyance/ application and evaporation losses) at the reproductive stage of the crop both for normal and drought years. Runoff during drought years is assumed to be 50 % of runoff surplus during normal rainfall years (based on authors' estimates for selected districts and rain-fed crops). However, farmers tend to use the water more prudently during drought years and save larger cropped areas. The potential irrigable area through supplementary irrigation for both scenarios is given in Table 5. Out of 114 billion cubic meters water available as surplus, about 28 billion cubic meters (19.4 %) is needed for providing supplemental irrigation to irrigate an area of 25 million ha during the normal monsoon year, thus leaving about 86 M ha-m (80.6 %) to meet river/environmental flow and other requirements. During drought years also about 31 billion cubic meters of water is still available even after making provision for irrigating 20.6 million ha. Thus it can be seen that water harvesting and supplemental irrigation do not jeopardize the available flows in rivers even during drought years or cause significant downstream effects in the identified areas.

Table 5. Irrigable area (‘000 ha) through supplemental irrigation (at 100 mm per irrigation) during normal and drought years under different rain-fed crops.

Crop group	Crop	Rain-fed crop area	Irrigable area during normal monsoon	Irrigable area during drought season
Cereals	Rice	6,329	6,329	6,215
	Finger millet	303	266	224
	Maize	2,443	2,251	1,684
	Pearl millet	1,818	1,370	837
Coarse cereals	Sorghum	2,938	2,628	1,856
Total (Coarse cereals)		7,502	6,515	4,601
Fiber	Cotton	3,177	2,656	1,725
	Castor	28	25	22
	Groundnut	1,663	1,096	710
	Sesame	1,052	919	741
	Soya beans	2,843	2,843	2,667
Oilseeds	Sunflower	98	59	30
Total (Oilseeds)		5,684	4,942	4,170
	Chickpea	3,006	2,925	2,560
Pulses	Pigeon pea	1,823	1,710	1,374
Total (Pulses)		4,829	4,635	3,934
Grand total		27,521	25,077	20,645

Source: Authors’ estimates

Rainwater Use Efficiency and Production Potential of Rain-fed Crops

Water use efficiency under rain-fed agriculture is not a consistent value as evidenced in irrigated agriculture. In rain-fed areas, the water use efficiency (WUE) varies from district to district and from year to year based on the pattern of rainfall occurrence with drought years giving a higher value of water use efficiency. The present study aggregates water use efficiency at the district level for major rain-fed crops. Production projections were made for different crops in the respective rain-fed districts using the information on regional rainwater use efficiency, both for ‘business as usual’ scenario (only application of supplementary irrigation) and under ‘improved practices’ scenario (limited follow-up on recommended package of practices). Additional production (Table 6) was a product of irrigable area (Table 5), regional rainwater use efficiency and the amount of supplemental irrigation. The irrigable area through supplemental irrigation for different crops during the drought season varies between 50-98 % (98 % for rice crop to 50 % for sunflower growing districts) of the irrigable area during the normal (non-drought) season. Under improved management practices, an average of 50 % increase in total production cutting across drought and normal seasons is realizable with supplemental irrigation from a rain-fed area of 27.5 M ha. Production enhancement in the drought season in case of rice crop is high due to higher water application efficiency and also due to sufficient surplus of to bring almost the entire rice cultivated area under supplemental irrigation. This would also indicate that large tracts of rain-fed rice cultivated area are covered under high rainfall zones with sufficient surplus for rainwater harvesting. Significant production improvements can be realized in rice, sorghum, maize, cotton, sesame, soybeans and chickpeas. The success of the ‘Green Revolution’ in irrigated areas is one solid example built upon irrigation and improved technologies. Every one of the stakeholders from supplier to farmer to market responded with equal enthusiasm. A second ‘Green Revolution’ is not in the offing for long time for the reason that this needs to be staged on a water- scarcity/insufficiency zone.

Table 6. Yield increases with supplemental irrigation (SI) in normal and drought seasons (based on WUE of improved technologies).

Crop group	Crop	Rain-fed cropped area	Traditional production (‘000 tonnes) (‘000 ha)	Irrigable area (‘000 ha)		Additional production (‘000 tonnes)	
				Normal season	Drought season	Normal season	Drought season
Cereals	Rice	6,329	7,612	6,329	6,215	4,141	4,357
Coarse cereals	Finger millet	303	271	266	224	124	112
	Maize	2,443	2,996	2,251	1,684	1,744	1,408
	Pearl millet	1,818	1,902	1,370	837	836	555
	Sorghum	2,938	3,131	2,628	1,856	2,439	1,864
Total	(Coarse cereals)	7,502	8,300	6,515	4,601	5,143	3,939
Fiber	Cotton	3,177	430	2,656	1,725	294	206
Oilseeds	Castor	28	10	25	22	6	6
	Groundnut	1,663	1,182	1,096	710	284	203
	Sesame	1,052	365	919	741	202	176
	Soya beans	2,843	2,607	2,843	2,667	1,429	1,443
	Sunflower	98	49	59	30	12	7
Total	(Oilseeds)	5,684	4,213	4,942	4,170	1,933	1,835
Pulses	Chickpea	3,006	2,367	2,925	2,560	1,061	1,000
	Pigeon pea	1,823	1,350	1,710	1,374	282	245
Total	(Pulses)	4,829	3,717	4,635	3,934	1,343	1,245
Grand total		27,521	24,272	25,077	20,645	12,854	11,582

Economics of Water Harvesting and Supplemental Irrigation

Supplemental irrigation has substantive potential for increasing production from rain-fed crops across different districts, yet its adoption on a large scale shall depend upon its economic worthiness. Numerous such structures have been built under varying agro-climatic conditions under state sponsored programs, by nongovernmental organizations and with individual initiatives. The available literature has good evidence on the technical and financial viability of construction of such water harvesting structures for, improvement of water productivity and diversification of agriculture in rain-fed areas (Singh 1986; Oweiss 1997). The cost of provision of supplemental irrigation through construction of water harvesting structures varies a great deal between different states/ regions and locations, and within the same state (Samra 2007; personal communication; Table 7). Hence, a simple analysis based on the national average cost for rainwater harvesting structures (INR 18,500/ ha) was carried out for the provision of supplemental irrigation to the rain-fed crops. In the calculation of annualized cost, rate of interest as well as depreciation cost for the structures has been deducted. An assumption was made that rainwater harvested would be utilized for the existing crop only, and accordingly returns were considered for the existing crop only. However, in actual practice the farmer makes much better use of the created water resource by planting high-value crops and plantations and investments in livestock and aquaculture. The annualized cost for each crop and gross and net benefits with supplemental irrigation to each crop are shown under Table 8. It suggests that an estimated INR 50 billion annually is required to provide supplemental irrigation to around 28 M ha of rain-fed cultivated land, and half of that amount is required for rice and coarse cereals only. The data suggests that gross and net benefits are quite high for cotton, oilseeds, pulses and rice. However, the coarse cereal group, in general, and pearl millet, in particular, exhibit lower gross and net benefits even with SI and improved practices. This indicates the need for better varieties of these crops, which are more responsive to irrigation and nutrition.

Table 7. Cost of different water harvesting structures per hectare of the service area at different locations in India.

Location	Cost of water harvesting structures (2000 price level)		
	Minimum	Maximum	Average
Bagbahrar (Chhatisgarh)	4,100	29,200	11,000
Dindori (Madhya Pradesh)	6,800	25,000	18,000
Keonjhar(Orissa)	19,400	35,000	27,000
Darisai(Jharkhand)	8,300	27,800	18,000
National Average			18,500

Source:J.S. Samra, personal communication, presentation made to the Planning Commission

Table 8. Crop-wise annualized cost and gross and net benefits (billion rupees) from supplementary irrigation with the harvested water.

Crop group	Crop	Rain-fed cropped area ('000 ha)	Annual cost	Gross benefit with SI and improved technologies	Net benefit with SI and improved technologies
Cereals	Rice	6,329	11.71	20.23	8.52
Coarse cereals	Finger millet	303	0.56	2.23	1.67
	Maize	2,443	4.52	7.05	2.53
	Pearl millet	1,818	3.36	1.88	-1.49
	Sorghum	2,938	5.44	6.38	0.95
Total (Coarse cereals)		7,502	13.88	17.54	3.66
Fiber	Cotton	3,177	5.88	14.15	8.27
Oilseeds	Castor	28	0.05	0.22	0.17
	Groundnut	1,663	3.08	8.86	5.79
	Sesame	1,052	1.95	6.82	4.87
	Soya beans	2,843	5.26	18.69	13.43
	Sunflower	98	0.18	0.36	0.18
Total (Oilseeds)		5,684	10.52	34.95	24.44
Pulses	Chickpea	3,006	5.56	49.05	43.49
	Pigeon pea	1,823	3.37	9.39	6.02
Total (Pulses)		4,829	8.93	58.44	49.51
Grand total		27,521	50.92	145.31	94.40

Conclusions

In spite of the rain-fed lands having the highest unexploited potential for growth**,** the risk of crop failures, low yields and the insecurity of livelihoods are high due to the random behavior of the rainfall. Rain-fed agriculture is mainly and negatively influenced by intermittent dry spells during the cropping season and, especially at critical growth stages coinciding with the terminal growth stage. District level analysis for different rain-fed crops in India showed that the difference in the district average yields for rain-fed crops among different rainfall zones was not very high, indicating that the total water availability may not be the major problem in different rainfall zones; and that for each crop there were few dominant districts, which contributed most to the total rain-fed crop production. A good strategy to realize the potential of rain-fed agriculture in India (and elsewhere) appears to be, to harvest a small part of available surplus runoff and reutilize it for supplemental irrigation at different critical crop growth stages. The study identified about 27.5 M ha of potential rain-fed area, which accounted for most of the rain-fed production and generated sufficient runoff (114 BCM) for harvesting and reutilization. It was possible to raise the rain-fed production by 50 % over this entire area through the application of a single supplementary irrigation (28 BCM) and some follow up on the improved practices. Extensive area coverage rather than intensive irrigation need to be followed in regions with higher than 750 mm/ annum rainfall, since there is a larger possibility of alleviating the in-season drought spells and ensuring a second crop with limited water application. This component may be made an integral component of the ongoing and new development schemes in the identified rural districts. The proposed strategy is environmentally benign, equitable**,** poverty-targeted and financially attractive to realize the untapped potential of rain-fed agriculture in India.

References

Agarwal, A. 2000.Try capturing the rain: Briefing paper for members of parliament and state legislatures—an occasional paper. Center for Science and Environment, New Delhi, India.

David, M. (ed.).2007. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earthscan, and Colombo: International Water Management Institute.

Falkenmark, M.; Rockstrom, J. 1993. Curbing rural exodus from tropical drylands. *Ambio* 22 (7): 427-437.

Irz, X.; Roe. T. 2000. Can the World Feed Itself? Some Insights from Growth Theory. *Agrekon* 39 (3): 513-528.

Joshi, P.K.; Jha, A.K.; Wani, S.P.; Joshi, L.; Shiyani, R.L. 2005. *Meta analysis to assess impact of watershed program and people's action.* Comprehensive Assessment Research Report 8. Colombo, Sri Lanka: International Water Management Institute.

Kanwar, J.S. 1999. Need for a future outlook and mandate for dryland agriculture in India. In. *Fifty Years of Dryland agricultural research in India*, eds. H.P. Singh et al. Central Research Institute for Dryland Agriculture, Hyderabad, India. pp 11-20.

Lobo, C. 2007.Distress in drylands: Need for better adaptation to technologies, institutions and policies for rain-fed areas. Water and People: Reflections in a Turbulent Pool- 6th IWMI-Tata Annual Partners' Meeting, March 8-10 Anand, India.

Oweiss, T.1997. Supplemental irrigation: A highly efficient water-use practice. Aleppo, Syria: International Center for Agricultural Research in Dry Areas.

Pretty, J.; Hine, R. 2001. Reducing Food Poverty with Sustainable Agriculture: A Summary of New Evidence. Final report of the "safe World" Research Report. University of Essex, UK.

Rego, T. J.; .Wani, S.P.; .Sahrawat, K.L.; Padhasardhy, G. 2005. Macro-benefits from boron, zinc and sulphur application in Indian SAT: A step for Grey to Green Revolution in Agriculture. Global Theme on Agro-ecosystems Report 16. Hyderabad, India: International Crops Research Institute for the Semi-Arid Tropics.

Reij, C .1988.Impact des techniques de conservation des eaux et du sol sur les rendements agricoles: analyse succincte des donnees disponsibles pour le plateau central au Burkina faso. CEDRES/ AGRISK.

Rockstrom, J. 2001.Green water security for the food makers of tomorrow: Windows of opportunity in drought-prone savannahs. *Water Science and Technology* 43 (4): 71-78.

Rockstrom, J.; Falkenmark, M. 2000. Semi-arid crop production from a hydrological perspective- Gap between potential and actual yields. *Critical Reviews in Plant Sciences* 19 (4): 319-346.

Rosegrant, M.; Ximing, C.; Cline, S.; Nakagawa, N.2002. *The role of rain-fed agriculture in the future of global food production.* EPTD Discussion Paper 90. Washington D.C., USA: International Food Policy Institute. (www.ifpri.org/divs/eptd/dp/papers/eptdp90.pdf)

Samra, J.S. 2007. *Personal communication*. Role of watersheds and Minor Irrigation in Food and Livelihood Securities. Presentation made before the Planning Commission. Government of India. New Delhi. June 29, 2007.

Sastry, G.; Reddy, Y.V.R.; Prakash, O. 2003. Impact of watershed management practices on sustainability of land productivity and socioeconomic status. (ROPS-14). National agriculture Technology Project. Central research Institute for Dryland Agriculture, Hyderabad, India.

Sharma, B.R..; Samra, J.S.; Scott, C.A.; Wani, S.P. (eds). 2005. Watershed Management Challenges: Improving Productivity, Resources and Livelihoods> International Water Management Institute, Colombo, Sri Lanka. 334 pp.

Sharma, B.R.; Smakhtin, V.U. 2004. Water harvesting as a strategic tool for drought mitigation in Southwest Asia. Proceedings of 55th International Meeting of the International Commission on Irrigation and Drainage, FAO/ ICID International Workshop on Water Harvesting and Sustainable Agriculture, Moscow, Russia. September 2004.

Sharma, K.D.1986. Runoff behavior of water harvesting micro catchments. *Agricultural Water Management* 11 (2): 137-144.

Singh, R.P. 2001.Watershed management: A holistic approach for dryland agriculture. National Workshop on Watershed Area Development: Challenges and Solutions, Indian Institute of Management, Lucknow, India. July 28-29, 2001.

Thirtle, C.; Beyers, L.; Lin, L.; Mckenzie-Hill, V.; Irz, X.; Wiggins, S.; Piesse. J. 2002. *The Impacts of Changes in Agricultural Productivity on the Incidence of Poverty in Developing Countries.* DFID Report 7946. London, UK: Department for International Development.

Wani, S.P.; Pathak, P.; Sreedevi, T.K.; Singh, H.P.; Singh, P. 2003. Efficient management of rainwater for increased crop productivity and groundwater recharge in Asia. In *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, eds. J. W. Kijne, R. Barker and D. Molden. Wallingford, UK: Colombo, Sri Lanka: CABI-IWMI. pp 199-215.

Wani, S.P.; Ramakrishna, Y.S. 2005. Sustainable management of rainwater through integrated watershed approach for improved rural livelihoods. In *Watershed Management Challenges: Improving Productivity, Resources and Livelihoods*, eds. B.R.Sharma et. al. International Water Management Institute, Colombo, Sri Lanka. pp.39-60.

Crop per Drop of Diesel! Energy-Squeeze on India’s Smallholder Irrigation

Tushaar Shah
International Water Management Institute, Anand, India

Introduction

1975-2000 was the golden age of smallholder irrigation in South Asia. Until then, much irrigation in the region was gravity flow, and confined to the command areas of canal systems and traditional irrigation structures such as tanks, ponds and ahar-pyne systems. Since 1975, the spontaneous boom in private investments in small boreholes and mechanized diesel and electric pumps has revolutionized irrigation agriculture, taking it beyond the command areas to the nook and corner of the sub-continent. This happened at a time when growing population pressure had made it imperative for marginal farmers to intensify their farming to ensure their families had food and to improve the security of their livelihoods. The mushrooming of local, informal, and fragmented pump irrigation service markets, through which the poor could access irrigation from pump owners, vastly expanded the productivity and equity impacts of this irrigation boom. Government policies supported the pump irrigation revolution through the expansion of institutional credit, a variety of subsidy schemes on borings and pumps, support to farm electrification and electricity subsidies. While pumps and boreholes emerged as the mainstay of smallholder irrigation, new concerns emerged about the threat of groundwater depletion, and about the adverse impacts of electricity subsidies on the viability of the electricity industry. How to cool this overheated pump irrigation economy emerged as one of the trickiest water policy issues in the region.

Since 2000, however, all available evidence suggests that the region’s groundwater economy has begun shrinking in response to a growing energy squeeze. This energy squeeze is a combined outcome of three factors: (a) progressive reduction in the quantity and quality of power supplied by power utilities to agriculture as a desperate means to contain farm power subsidies; (b) growing difficulty and rising capital cost of acquiring new electricity connections for tubewells; and (c) an eight-fold increase in the nominal price of diesel during 1990-2007 (a period during which the nominal rice price rose by less than 50 %). In a survey we carried out in 2002 interviewing over 2,600 tubewell owners in India, Pakistan, Nepal terai and Bangladesh, who unanimously ranked ‘energy cost and availability’ as the top challenge to their farming, far above ‘groundwater depletion’; ‘high rate of well failure’; and ‘rising groundwater salinity’. Since the time of our survey, diesel prices have jumped over 70 %. Hence, it is no surprise that the diesel price squeeze on small-scale irrigation is heading towards a crisis in all the countries of South Asia in general, and is particularly visible in eastern India and Nepal terai, where the ratio of rice to diesel price has turned particularly adverse as evident in Table 1.

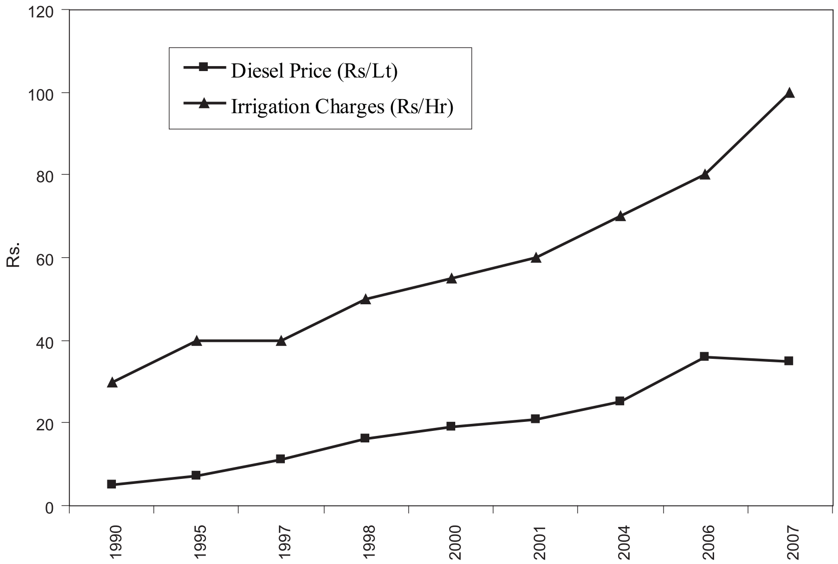
Table 1. Farm-gate rice price relative to diesel price in countries of South Asia.

	Diesel price: February 2007	Farm-gate rice price: February 2007	Kg. of rice needed to buy a liter of diesel
India (Indian Rs.)	34.0	6.4	5.7
Pakistan (Pakistan. Rs.)	37.8	11.8	3.2
Bangladesh (Taka)	35.0	9.0	3.9
Nepal terai (Nepal Rs.)	57.0	10.0	5.7

Source: Field research results by IWMI researchers

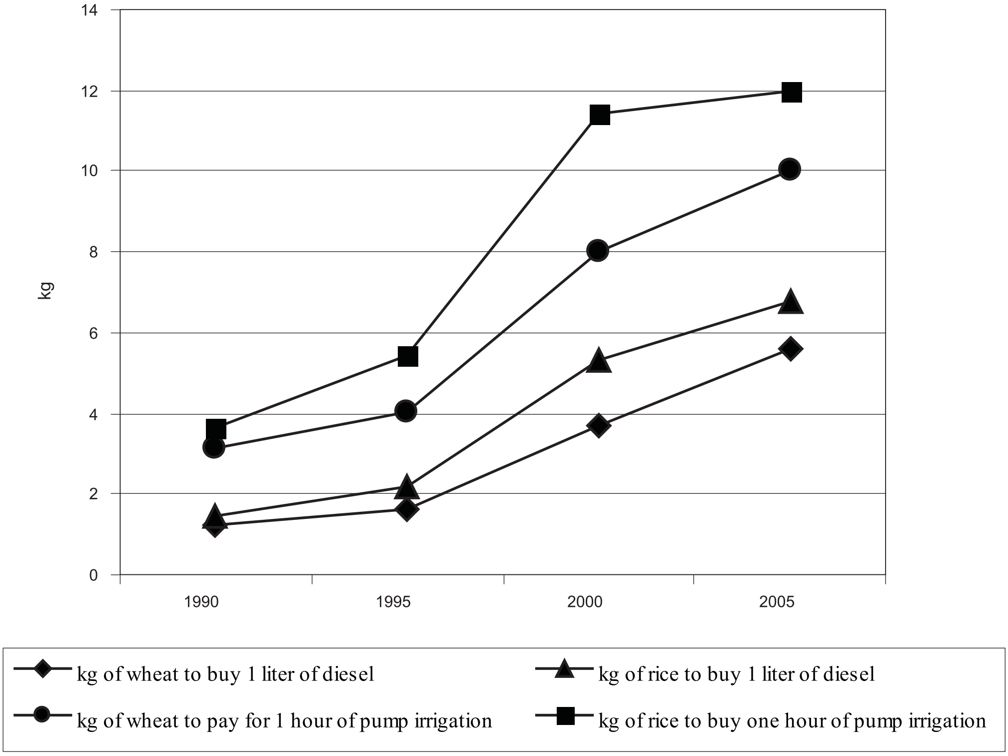
Of even greater significance for the poor is the increase of pump rental prices consequent to the rise in diesel prices. The poorest strata of India's peasantry depend on water markets for securing their irrigation, but because water markets are natural oligopolies (Shah 1993), pump owners use diesel price increases to raise their pump rental rates in tandem with every major rise in diesel price, despite the fact that pumps themselves have become cheaper during 1990-2007. Figure 1 shows the changes in the nominal price of diesel versus the price of pump irrigation in Mirzapur, Uttar Pradesh (Singh, O.P.). Between 1990-2007, diesel prices have risen from Rs. 4.6 to Rs. 34.8 per liter; but the rate incurred by buyers of pump irrigation has been an increase from Rs. 23-25/hour to Rs. 90-95/hour, far more than what is needed to cover the increase in fuel cost. Another characteristic of this relationship between diesel an pump irrigation prices, is the downward stickiness of pump irrigation prices; although every time there is a significant increase in the diesel price, pump irrigation prices tend to jump high, the reverse is never the case.

Figure 1. Diesel price rise and pump irrigation price: Mirzapur, UP.



As a result, pump rentals relative to farm produce prices—which are what matter to the marginal farmers and sharecroppers—have risen even faster than diesel prices relative to rice and wheat prices. In 1990, a farmer in Deoria of eastern Uttar Pradesh could buy an hour of pump irrigation for the farm-gate price of a little over 3 kg of rice and wheat. Today, this ratio is 10 kg of wheat and 12 kg of rice (see Figure 2)—(Singh, Yashwant).

Figure 2. Deoria: Relative price of diesel and diesel pump irrigation with respect to farm-gate food prices.



Electric tubewells, subject to flat horse-power linked tariff, are cheaper to operate than diesel pumps because their owners sell pump irrigation at much lower rates than diesel pump owners. Therefore, new electricity connections are avidly sought after. However, most states—which in the early 1960s gave district collectors monthly targets for the minimum number of tubewells to be electrified—now operate an embargo on new electricity connections to tubewells. And where they are issued, the entire cost of taking the power line to the tubewell i.e., of poles, cables and transformers is charged to the farmer. This has made new electricity connections scarce as well as prohibitively costly. Even so, existing electric tubewell owners and marginal farmers who are close enough to their tubewells to buy pump irrigation from them, are luckier compared to diesel pump owners and their buyers as is evident from Table 2. Since farmers who can buy pump irrigation from electric tubewell owners incur a lower cost than using their own diesel pumps, diesel pump owners in Uttar Pradesh, too, prefer purchased irrigation from electric tubewells than irrigating with their own diesel pumps.

Table 2. Cost of irrigating an acre of sugarcane in the Akataha Village, in the Deoria District of eastern UP (Singh, Yashwant).

	Diesel pump	Electric pump
Own irrigation source	Rs. 1,620/acre	Rs. 37/acre
Purchased pump irrigation	Rs 3,780/acre	Rs. 1,080/acre

This paper summarizes the results of studies we carried out in 15 villages, located in different parts of India. These studies were conducted with the participation of location-based researchers and are aimed at developing a first-cut assessment of the varied impacts of the energy squeeze on smallholder irrigation with groundwater, which has become a dominant factor in Indian agriculture during the recent decades. The aim of the studies was to explore, identify and document rather than to measure and quantify these impacts. In the opinion of our research partners, the only way we can analyze whether certain impacts were more widespread than others is by enumerating the number of case study villages where these occurred. This enumeration is set out in Table 3, which suggests that the groundwater economy in many parts of India, especially in the east, is shrinking. Furthermore, marginal farmers and sharecroppers are seen to have borne the brunt of the energy squeeze, and are fashioning a variety of desperate responses in order to survive in irrigation.

Table 3. The three most important responses of farmers in the study villages to the energy squeeze.

	Village study location	Most important response	Second most important response	Third most important response
1.	Kendradangal, Birbhum, West Bengal	Decline in pump irrigated boro rice area	Marginal farmers and sharecroppers exit farming	Kerosene/crude as a diesel substitute
2.	Kaya, Murshidabad, West Bengal	Shift to low-water using crops	Chinese pump-sets	Kerosene as a diesel-substitute
3.	Ferozpur Ranyan, Haryana	Give fewer irrigations; same crop pattern	Water conveyance through pipes	Exodus of marginal farmers from farming
4.	Purana Pradhan, Khurda, Coastal Orissa	Install electric pump or buy from electrified borewells	Switch to high-value crops	Move out of pump irrigated agriculture
5.	Badhkummed, Ujjain, Madhya Pradesh	Turned to electric pumps	Decline in diesel pump irrigated area	Irrigate fewer times
6.	Berkhedakurmi, Sehore, Madhya Pradesh	Increase in irrigation with electric pumps	Decline in area under diesel pump irrigation	Switch from sugarcane to wheat and gram
7.	Lilapur, Rajkot, Gujarat	20-25% decline in rabi irrigation	Increased irrigation interval	Small bed and alternate furrow irrigation
8.	Jawrabodi, Vidarbha, Maharashtra	Increased irrigation interval	Optimizing on rainfall/ life-saving irrigation	Reduced irrigated area

	Village study location	Most important response	Second most important response	Third most important response
9.	Keotkuchi, Barpeta, Assam	Diesel pumps run on kerosene	Decline in pump irrigation	Farmers quitting farming
10.	Dharamgarh, Kalahandi, Orissa	Increased use of canal irrigation and manual lifting	High-value crops	Longer irrigation interval
11.	Shergarh, Hoshiarpur, Punjab	Farmers lease out lands to Bihar laborers	Distress shift to off-farm livelihoods	Optimizing water application
12.	Veerpur, Banswara, Rajasthan	Kerosene used to run diesel pumps	Longer irrigation interval	Pump irrigation concentrated on vegetables for market
13.	Simra, Phulwari, Bihar	Return to rain-fed paddy in kharif and pulses in rabi	Pump irrigation concentrated on summer onion for market	Share-cropping with purchased irrigation declining
14.	Akataha, Deoria, Eastern UP	Increased dependence on flow irrigation	Pump irrigation concentrated on high-value crops	Longer irrigation interval
15.	Abakpur Mobana, Mirzapur, Uttar Pradesh	Pump irrigation concentrated on cash crops	Irrigation interval longer	Water saving crops

Source: Farm survey in 15 villages

Withering Water Markets?

Most social impacts of the energy squeeze on smallholder irrigation—and the agrarian poor—are felt through groundwater markets. Before and around 1990, when diesel was one-eighth its price today and farm power supply better than today, electric tubewell owners, in spite of enjoying natural oligopolies**,** were forced to behave in a highly competitive market (Shah 1993). Flat electricity tariffs, which reduced the marginal cost of pumping to near-zero levels, created a powerful incentive for electric tubewell owners to maximize pump irrigation sale, and in the process pare down the prices. Diesel pump operators were able to offer some competition because of a) low diesel prices b) portability of diesel pumps facilitating the irrigation of areas that could not be reached by electric tubewells. Numerous field-based studies showed that such local groundwater markets emerged as the mainstay of ultra-marginal farmers and sharecroppers, especially in eastern India and Bangladesh. In Bangladesh, Fujita and Hussain (1995) noted that owing to pump irrigation markets, 'the economic value of land... has decreased in a relative sense' in the farm income generation and 'opportunities for the landless and near-landless to climb the social ladder (have) expanded greatly'. In Uttar Pradesh, Niranjan Pant (2005) wrote: "...the smallest farmers with landholdings of up to 0.4 ha are the largest beneficiaries of the groundwater markets, as 60 % of the farmers of this category irrigated their wheat crop by water purchased from the owners of private Water Extraction Devices..." Shah and Ballabh (1997), based on a study of water markets in six villages in North Bihar, concluded that the markets had opened new production possibilities for the poor that left them better off than before, and that thereby imparted a new dynamism to the region's peasant economy. Even Wilson (2002), otherwise critical of profiteering by water sellers in Bihar, wrote: "extension of irrigation through hiring out (mobile diesel pump sets) to small- and marginal-holdings is, in fact, the major factor accounting for the further increase since 1981-82 in cultivated area irrigated at least once to approximately 73 % in 1995-96. Those hiring in pump sets are overwhelmingly small and marginal cultivators; they cultivate an average of 1.35 acres (compared with an average of 3.89 acres cultivated by pump-set owners)..." Most recently, Mukherji (2006) in an extensive study of water markets in West Bengal reaffirmed their myriad benefits to the agrarian poor. Water markets, and indeed groundwater irrigation itself, have been a source of much succor to the agrarian poor. Studying rural poverty ratios across the Indian states over five points between 1973/74 and 1993/94, Narayanmorthy (2007) concluded that, "there is a significant inverse relationship between the availability of groundwater irrigation and the percentage of rural poverty..."

With soaring diesel prices and a shrinking power supply to tubewells, this happy situation has rapidly changed for the worse. Pump irrigation markets—which boomed during the 1980s and 1990s and probably served more areas than all public irrigation systems in India (Mukherji 2005)—are shrinking rapidly; and so is the size of the groundwater irrigation economy itself. During the 1980s and 1990s millions of farmers in northern and eastern India purchased diesel pumps, often as stand-bys for their increasingly unreliable electric pumps. Now this situation has come full circle; with diesel becoming unaffordable, especially for water buyers, the preference for electric tubewells has increased, but it is a preference that is largely unmet because electricity supplies as well as connections are dwindling.

In eastern India, Nepal terai and Bangladesh, electric tubewells are few and far between. Where we find them, two impacts follow: first, their owners find their monopoly power enhanced, which they use to increase their share in groundwater markets and irrigation surplus; second, they are able to moderate the energy squeeze on marginal farmers, especially when the power supply situation is good and tubewell owners pay flat electricity tariffs. We found this to be the case in Uttar Pradesh, West Bengal and Orissa. Where they are found in significant numbers, electric tubewell owners have driven diesel pump owners out of business. So unequal is the competition that even owners of diesel pumps prefer to purchase irrigation from electric tubewell owners rather than use their own diesel pumps (Mukherji 2005). In UP, a 5-hp electric tubewell connection is a 'cash-cow' for its owner as it entails a monthly charge of only Rs. 410 but can generate up to Rs 9,000/month as gross income from the sale of water, which is a highly profitable proposition (Singh. O.P.). In Birbhum, West Bengal, our researcher wrote, "... by charging such a high price for electric pump irrigation, the submersible owners are getting their own irrigation free of cost and, on top of that, they make some profit as well"(Chowdhury). Here, the flat tariff paid by electric submersible pump users increased from Rs. 5,460/year to Rs. 8,950/year between 1990 and 2007. In response, irrigation rates charged for boro rice too doubled from Rs. 450/bigha to Rs. 900/bigha. This rise was much smaller than the rise in the cost of purchased diesel pump irrigation, which has diverted the diesel pump owners' business to electric tubewell owners and strengthened their monopoly power. While electric submersible owners make merry, it is also increasingly the case that the marginal farmers of Bengal can grow boro rice only if they can tie up irrigation with an electric shallow/mini-deep tubewell owner.

The succor private electric tubewells can provide to the poor is limited by the West Bengal government's policy, which seems to be designed to minimize new connections for electric tubewells and ensure that the poor do not get them. To promote boro irrigation, the government had a scheme to issue temporary seasonal connections. In 2003, temporary connections were offered to Birbhum farmers for boro rice at Rs. 7,000 for 3 months; and in our study village, seven diesel pump owners took advantage of this offer, but the next year, the tariff was increased to Rs. 18,000, which put paid to the boro season electrification scheme. Permanent connections are preferred by all, but take 3-4 years to get approved and are prohibitive in cost, e.g., Rs. 1.25 – 1.3 lakhs for poles, 11 KV cables, a 10 KW transformer and an electronic meter. The only farmer in our study village who has so far been able to afford such a mini-deep connection had 7 acres of his own land and 5 acres of neighboring lands to command.

The ability of flat-tariff paying electric tubewells to moderate the impact of the diesel price squeeze is undermined by three factors: (a) inadequate supply of new electricity connections for irrigation; (we studied b) the prohibitively high cost of installing new connections; and (c) low amount and quality of power supply to agriculture. We found new electricity connections easily and quickly available in Uttar Pradesh; but the demand was subdued because the farmer has to pay for the cost of laying the cable, poles and transformer, too—which may add up to Rs. 100,000 or more (Singh, O.P.). In the Kalahandi villages in Orissa, we found electricity supply in plentiful and electric tubewells costing one-seventh of the cost of operating a diesel pump of comparable output. However, an electric pump 500 m away from the village may cost Rs. 40,000 in cables and poles besides the cost of the well, pump-set pump house, starter, etc. As a result, in our study village, we found only six large holding farmers owned electric pumps while small farmers managed with their own or rented diesel pumps. These large holding farmers are able to earn Rs. 30-35 thousand net/year from their tubewells in crop-sharing contracts, which implies a decent rate of return on their capital investment. However, the entry-barrier of high capital costs prevents smallholders from availing themselves of this benefit (Nayak). In West Bengal, even if the farmers were willing to incur such high costs, connections were hard to come by in many areas primarily because the State Water Investigation Department (SWID) expressed a sometimes exaggerated concern about over-exploitation of the groundwater resource.

In Bihar, all the three disabling factors were in full play. In a rare exception, in the study village Simra in the Patna District, we found over 100 electric tubewells in operation. But since the uncertain, halting and mostly night-time supply of power in the village never exceeds 6 hours/day, and that too with a dozen or more power-interruptions, the water buyers had to depend heavily on renting diesel pumps at Rs. 35/hour (excluding fuel and Mobil) as electric pump owners had hardly enough electricity to irrigate their own crops (Chaube).

The only location—out of the 15 we studied across India—where the energy squeeze left farming unperturbed was water-abundant Kerala (Raphael). Diesel pump irrigation disappeared from Kerala way back in the 1970s as the government laid electricity infrastructure in every nook and corner of the country. However, Kerala agriculture—and its irrigation—are in the throes of profound change. The state invested large sums in creating paddy irrigation infrastructure, but due to labor and land shortages, soaring farm wage rates, and a roaring money-order economy, the land use in Kerala is rapidly shifting away from paddy cultivation and towards plantation crops, mainly rubber, banana, areca nut and coconut. Much of the plantation economy is built around homesteads where dug-wells, augmented by bores at the bottom, double for domestic use as well as for watering the home garden. Farmers lift the small quantity of water needed to water their trees manually or use small electric motor-pumps. The village we covered, Thekkamkara from the Trichur District, was an atypical Kerala village with a proliferation of kerosene pumps. Although the energy squeeze is not a serious issue here, the government has a scheme to supply 3 liters/month of subsidized kerosene per acre to smallholders to cushion the energy shock. A 1.5 hp kerosene pump can lift 25 m^3 of water and irrigate an acre of land in 4 hours. The energy cost of irrigation here must be less than 5 % of the value of output it supports, compared to the 25-35 % of northern and eastern India. Yet, we found a small political economy woven around the kerosene distribution in Trichur.

Return to Rain-fed Farming

Leaving aside Kerala, elsewhere in India, the energy squeeze is folding up the pump irrigation economy. Way back in the 1970s, economist Ishikawa called ‘irrigation’ the leading input in agricultural growth (Ishikawa 1967). Post-1975, India’s smallholder agriculture boomed with supplemental irrigation made possible by diesel and electric pumps. However, all the evidence we have suggests that the energy squeeze is forcing farmers, especially the marginal farmers and sharecroppers, to economize or even give up on this ‘leading input’. In groundwater-rich eastern Uttar Pradesh and Bihar, marginal farmers are withdrawing from wheat and sugarcane cultivation because they cannot afford the cost of using rented diesel pumps for supplemental irrigation. In Gujarat (Talati) as well as Vidarbha (Mardikar), our case studies showed that farmers dependent on rented diesel pumps are quitting rabi wheat cultivation, replacing it with the cultivation of rain-fed gram and other pulses. In West Bengal (and Bangladesh), all available evidence suggests that smallholding farmers are compelled to give up boro rice cultivation, which has served as their food security passport for over two decades. In the Kaya village of Murshidabad, we found that the most significant impact of rising diesel prices was the decline in the boro rice area from constituting about 50 % of the village’s farm land in the early 1990s to 20 % or less today (Banerjee).

There is a strong scale-bias in the shrinking of the boro rice area, with the agrarian poor being the hardest hit. This was put in bold relief by the case study of Kendradangal village in the Birbhum District in West Bengal. Electric tubewells, generally owned by influential upper caste farmers, covered most of the village lands, barring a small pocket of 70 ha with small parcels owned by the Schedule Caste (SC) families. Post-1985, when the boro rice revolution overran Bengal, the electrified parts of the village experienced a productivity boom, however, the SC families too were able to irrigate boro rice with the help of 25 diesel pumps. Come 2005, as a result of soaring diesel prices, only nine SC diesel pumps were in use, and in the summer of 2006 the number dwindled to three. While the electrified part of Kendradangal continues with its boro rice binge, the SC farmers we interviewed lamented: “diesel pumps are fit to be thrown into the compost pit.” Between 1990 and 2006, boro rice irrigated with diesel shallows in the SC lands in Kendradangal fell from 60 ha to 16 ha (Chowdhury). In the Kaya village of Murshidabad, SC farmers told us: “For us, all the positive effect of green revolution has been nullified due to diesel price hikes…boro paddy played a great role so far in feeding our families; in *amon,* it is impossible to grow the family’s rice requirement without cultivating a large field;

but in boro, because of the very high yield, we could lease small plots and grow enough food for the family; but now boro paddy is beyond the reach of us marginal farmers" (Banerjee)..

In the canal villages we covered in Kalahandi in Orissa, with diesel pump irrigation rates soaring from Rs. 25/hour in 1995 to Rs. 60 in 2007, pump rental markets have shrunk. Many *mali* farmers in this high-water table area took to the manual irrigation of vegetables by pots or by lifting water using *dhenkuli* from a depth of 10 feet in their 4 feet diameter open wells. Moreover, farmers renting diesel pumps shifted to diesel-saving water melons on river banks besides taking to more diversified rain-fed crops. In general, turning to rain-fed cultivation of field crops like groundnut and black gram while expanding vegetable cultivation with pump irrigation for the nearby town —brinjal, cabbage, potato and water melon, all of which are capital intensive and risky but produce high cash per decimal of land—are the twin elements of the dominant livelihood strategy by small and marginal farmers in these wet villages. A similar transition from pump irrigated crops to rain-fed crops was noted in drier areas as well. In the Gujarat village in the Rajkot District, we found poor farmers giving up winter wheat to take to gram and pulses, besides some BT cotton. In Ujjain, Madhya Pradesh, we found them switching from irrigation-dependent sugarcane, cotton and groundnut to rain-fed soybean and gram. In gram, too, we found farmers taking to a drought-resistant 'dollar' variety, giving up traditional varieties that gave better yield but needed an irrigation or two (Sharma).

Sharecropper Under Siege

The groundwater boom had powerful labor absorption impacts on agriculture, but these are now on the wane. In the Murshidabad village of Kaya, the decline in boro paddy and jute cultivation depressed the demand for labor -especially boro paddy was much valued by the marginal farmers since it absorbed family labor in productive subsistence farming. With boro paddy on the decline, men folk of landless and marginal farmer households have been looking for work in brick kilns, NREGP work or rickshaw-pulling; and disguised unemployment among women has risen. In the Simra village of Patna, Bihar, farm wage rates were Rs.15 in cash and 2 kg of rice, about the lowest in all the villages we covered. On onion fields, the wages offered were 5 kg of onion; and on masoor harvesting, it was one bundle for every 18 bundles harvested. To make matters worse, the highly elastic labor supply from neighboring villages kept Simra's farm wages at these depressed rates (Chaube).

Leasing small parcels of land for a fixed annual rent has been an important way for the landless to employ family labor to ensure food security. In Simra, in such *Nagdi Batai* (or Cash Tenancy) contracts, a landless family leases a hectare of land from an absentee land owner for a cash rent of Rs. 14,000-Rs. 20,000/year; and cultivates it with purchased pump irrigation. But this form of tenancy is on the decline because the landless and marginal farmers, 75 % of Simra's households, find it increasingly difficult to make their tenancy viable. In Kendradangal, a Birbhum village, we were told that marginal farmers with diesel pumps shared a common practice until 2000 of leasing land for boro rice cultivation. However, with rising diesel prices, this practice has all but disappeared; in 2006 only three marginal farmers leased land, and that too only six or seven bigha's for boro cultivation. In the Kaya village of Murshidabad, similarly, until a few years ago, it was common practice for the landless or marginal farmers to lease small parcels of land for an annual rent of Rs. 1,800-2,000/bigha

(Rs. 13,500-15,000/ha), and they would still manage to grow crops like boro rice or vegetables by buying diesel pump irrigation. With the present prices of diesel pump irrigation, however, this practice has almost ended with half or more of the boro production claimed by the providers of land and water alone.

Instead of cash tenancy, crop-sharing for water is on the rise in some parts of India. In the Rajkot village of Saurashtra, Gujarat, water buyers depend on renting diesel pumps only for supplemental irrigation in the kharif and renting diesel pumps for rabi crops, once a widespread practice, has completely disappeared. Electric tubewell owners (who under Gujarat's new Jyotirgram Scheme get 8 hours of uninterrupted, full voltage power under a fairly high albeit flat charge of Rs. 850/hp/year [Shah et. al. 2007]) have moved in as aggressive sellers of pump irrigation service during the rabi. The common arrangement is crop sharing rather than cash sales: the land owner provides land and labor; the tubewell owner provides pump irrigation service; both parties share other costs and output on a 50:50 basis. In this deal, then, the value of pump irrigation is equivalent to both land as well as labor.

Rise in diesel prices has increased the rental value of surface irrigated land wherever surface irrigation is reliable. In the tail-end of the Upper Indravati system in the Kalahandi District of Orissa, Nayak reported that the annual rent charged by command area farmers for one-tenth of a hectare rented for vegetable cultivation is Rs.1, 000/year, while the rent for a similar sized plot outside the canal command is just Rs. 250/year.

In the Kalahandi villages that we covered in Orissa, electric pump owners generally provide irrigation service on a share-cropping basis and earn Rs. 30-35 thousand annually from water selling. In a standard contract, the pump owning large holding farmer contributes land and irrigation usually for groundnut, while the tenant contributes labor; both parties share each others' costs and output on a 50:50 basis. If a small farmer contributes land and labor and the pump owner contributes just irrigation, then the latter absorbs all the costs of other inputs—mainly seeds and fertilizer; and both share the output equally.

In coastal Orissa's Purana Pradhan village, the cost price-squeeze has forced many landless and marginal farmers to move to off-farm occupations. Happily, this has made more land available for the remaining landless to lease for short-term crops like summer paddy as well as round the year vegetable cultivation. Even some women of the landless families now work on crop-share contracts rather than as casual farm workers (Satpathy).

The Hierarchy of Exit

In many of our case study villages, we discerned a curious hierarchy of exit from diesel pump irrigated farming i.e., small and medium farmers migrate out of unviable irrigated farming while poorer households 'reverse-migrate' back into irrigated farming. This was evident in Keotkuchi, study village of Assam (Dasgupta). In this flood-prone village, kharif paddy, always at the risk of a wash out, is a low-input-low-output affair. But farmers grow mustard, potato or vegetables soon after the kharif paddy and then grow their main crop of summer paddy. This input and irrigation intensive crop of summer paddy with an assured yield of around 7 mt/ha got a strong fillip during the 1990s when the government supplied a large number of diesel pumps at subsidized rates. But now, summer paddy is on the decline, primarily due to the soaring diesel prices. No matter how the farm budgets are worked out, summer paddy does not generate any surplus for a farmer who views his farm as an economic enterprise. Therefore, most farmers in Keotkuchi who could find off-farm work have gone ahead and done so, selling their diesel pumps at throw-away prices, and leaving their farming to either large farmers or sharecroppers. The village is surrounded by villages full of hard-working landless Bangladeshi Muslims whose priorities are two fold: a) food security by growing their own rice; and b) put their free family labor to productive use. These people bought the diesel pumps from the 'yesterday's' farmers of Keotkuchi at throw-away prices, and lease their paddy land in the summer, irrigating their summer paddy with kerosene or a kerosene-diesel mix. The other classes of farmers who have survived the energy-squeeze are the large holding farmers who could invest in electric pumps, diesel pumps, tractors and 'gensets' and optimize on the irrigation cost as well as quality.[1]

A similar hierarchy of exit from farming was noted in the more mechanized agriculture of Punjab (Misra[a]), Haryana (Misra[b]) and Madhya Pradesh (SRIJAN). Here, soaring diesel prices have been affecting smallholder farming through its leveraged impact not only on pump irrigation but also on the rental rates of other machine services, mainly ploughing and threshing. With water tables down to 60-70 feet, 150-300 feet deep tubewells with submersible pumps are needed to access groundwater irrigation. The investment required may exceed Rs. 1.2 lakhs and, as such, only large and some medium farmers would be able to afford such investments. Since tractors are often used to run generator sets (gensets), farmers who have tractors and deep tubewells with submersible pumps enjoy economies of scope in the agrarian economy. Small farmers however, who depend on the rentals of all machines find the going to be tough. Since electric tubewell owners get hardly enough electricity to irrigate their own fields, their customers have to contend with 'genset irrigation' which may cost up to Rs. 1,100/day to water 4-5 hectares. In our study of a village in Malwa, giving five irrigations to a bigha of wheat with a tractor-powered genset can cost Rs. 3,500 upwards, at which cost wheat cultivation becomes an unviable proposition (Sharma). So only those farmers who grow wheat and have electric pumps or can crop-share with electric pump owners irrigate farming; the rest turn to 'rain-fed' crops or quit farming altogether. In response to squeezed margins in farming, many smallholders in Punjab and Haryana have been leasing out parts or all of their holdings to even poorer migrant laborers from Bihar and Madhya Pradesh at Rs. 8,000-9,000/acre/year of flat rent, while they themselves move to off-farm jobs. The migrant laborers, whose first concern is to get full-employment wage rates, rather than secure a profit, make their farming viable by substituting muscle power for machine power and through the super-intensive cultivation of high-value crops for the market. It is these reverse migrants into farming— the marginal farmers who are unable to find off-farm livelihoods— are bearing the brunt of the energy squeeze.

At the bottom of the agrarian pyramid, the energy squeeze and the cropping pattern changes it brings about are influencing women's role in the agrarian economies in a myriad of ways. In Murshidabad, we found that the decline in boro cultivation has a curtailing effect on the rice-boiling cottage industry, which is dominated and controlled by poor women. In the Deoria village, decline in the paddy area affected a reduction in the demand for female labor

---

[1] In Keotkuchi, the archetype of this latter class was Nirmal Chandra Das, who added 100 bigha of leased land to his own 60 bigha farm, gave up diesel-intensive summer paddy all together and developed a diversified cropping pattern in the rabi to make his farming operation viable.

for transplanting work. Hence, women in this village took to goat rearing. In Abakpur Monga in Mirzapur, UP expansion in vegetable crops, especially peas, has increased the demand for labor and created new employment opportunities and higher wage rates for poor women laborers. And almost everywhere, we found the energy squeeze on irrigated agriculture increased the role of livestock and dairying, further transforming the position of women in the household economies of the poor.

Chinese Pumps to the Aid of Bengal's Agrarian Poor

In West Bengal, help has come to the 'energy squeezed' farmer from unlikely quarters: Chinese kerosene-cum-diesel pumps. Boro rice is far more intensive in working capital, labor and irrigation than other rice crops, but it is effective in land-saving and, therefore, appealing to marginal farmers and sharecroppers alike. It offers 7 mt/ha of rice yield against barely 1-1.5 mt/ha rain-fed *amon* (kharif) rice. Growing a small parcel of boro rice may liberate a farming family from subsistence worries for the whole year and, therefore, it is prized by the poor. For want of better alternatives, such as electric pumps, West Bengal's marginal farmers have been switching to Chinese pumps with gusto. They are cheaper to buy, costing Rs. 7,000 and Rs. 8,500 for 3.5 and 5 hp pumps respectively, when compared with Rs. 16,000 for a 5 hp diesel pumps made in India. The Chinese 5 hp pump runs for 2 hours from a liter of diesel, which a local pump of 5 hp burns in an hour or less. Finally, while a local pump needs a bullock cart to move around, the Chinese pump can be easily carried by a farmer on his shoulders.

Within approximately only 5 years, Chinese pumps have captured the irrigation pump market in West Bengal. In Murshidabad, all 30 diesel-run shallows in Kaya, our study village, used Chinese pumps. Boro rice boom here was originally fed way back in the 1970s and 1980s, by co-operative tubewells with electric pumps founded by an NGO. However, the co-ops failed, as they did elsewhere also (Pant 1984). But the boro rice boom continued during the 1990s with the help of Indian pumps. The rising diesel price however, has led the Indian pumps to be considered 'fir for composit pit', and led the Chinese pumps to become one of the most popular alternatives to the Indian pump.

How did the Chinese pumps make in-roads into West Bengal's irrigation scene remains somewhat of a mystery. Apparently, certain second-hand Chinese pumps smuggled across the Bangladesh border found the farmers' fancy; and soon enough, there followed a deluge of Chinese pumps smuggled across the Bangladesh border. It was only a matter of time before official imports began in 1998. Now, out of every 100 new diesel pump assemblies purchased in these parts of West Bengal, over 90 have Chinese engines. Kolkata has emerged as the epicenter of Chinese pump diffusion. Several brands of Chinese and Chinese-Indian pump assemblies are on offer here and are selling at 35-40 % less than the price of Kirloskar 4 and 5 hp engines, which remained market leaders for decades. Interviews with pump dealers in Kolkata confirmed that farmers preferred these Chinese pumps for their low price, their much higher fuel efficiency (0.35-0.4 l/hour), their ability to work on kerosene, and their easy portability. Chinese pumps, however, suffer more wear and tear and have shorter life span. Nevertheless, Chinese pump mechanics have emerged in every village; and their spare parts are cheaper and readily available.

PDS Kerosene: For the Kitchen or the Farm?

Close on the heels of Chinese pumps has emerged a new trend throughout India, of using subsidized PDS[2] kerosene, usually meant for cooking, to run irrigation pumps. Against the fact that it reduces the life of the engine, poor farmers see two advantages in using kerosene: first, PDS kerosene, subsidized as a cooking fuel, is cheaper than diesel; second, used with Chinese pumps, it yields more water per liter, *ceteris paribus*. Extensive use of kerosene and crude oil to run diesel pumps is the litmus test of how hard the energy squeeze pinches pump irrigators. Some engines, particularly Chinese ones, are designed to use diesel as well as kerosene. In Kalahandi (Orissa) villages, we found that marginal *mali* farmers, traditional vegetable growers, have chucked aside their diesel engines and taken to 1.5 hp kerosene pumps for irrigating their onion crop, with 3'*2' *kyari's* on a 0.25-0.5 ha parcel of land. But we found that scheduled caste marginal farmers in Birbhum, would run Kirloskars also on kerosene: "In what way can you call this a diesel pump?" they mocked about their pumps.

In many parts of eastern India, collecting the PDS quota of subsidized kerosene, meant for cooking, and storing it for irrigating a Rabi or summer crop has increasingly become a standard operating procedure for many poor households. Sharecroppers and marginal farmers with large families have special advantages as well as compulsions: large family means more kerosene allotment from fair price shops; it also means freedom from using hired labor at peak wage rates. Large family also means urgency in growing boro rice for family subsistence.

PDS kerosene, then, has emerged as a key player in West Bengal's political economy of boro rice cultivation. Increasingly, the task of storing PDS kerosene for boro rice irrigation has been taken over by operators of PDS outlets themselves, who wait for the onset of the boro season to release their stockpile of PDS kerosene. With this, switching to kerosene too has ceased to be of much help since it is the traders who have begun to skim the cream in the black markets for PDS kerosene: between 1990 and 2006, diesel price went up from Rs. 4/l to Rs. 34.30/l in Murshidabad villages; but kerosene price in the black market too rose from Rs. 8/l to Rs. 25/l, wiping out some of the cost relief offered by kerosene to the poor in fending off the energy squeeze (Banerjee).

Diesel-efficient Irrigation Options

Expectedly, the rise in pump irrigation costs has forced farmers to search for diesel-efficient irrigation options—including crop choices, irrigation techniques and fuel options. In the Rajkot villages in Gujarat, we found farmers adopting small-bed irrigation in winter crops such as cumin, gram and wheat, and alternate furrow irrigation for cotton. They told us these can save 20-25 % of diesel but reduce crop yield/bigha by a quintal in cotton as well as in wheat. In our UP village in the Mirzapur District, to save on irrigation costs, farmers have begun applying four irrigations to the rabi wheat crop rather than the usual five they have been applying all these years. In our Birbhum village of West Bengal, we found that many sharecroppers leased parcels just below their own land so as to use the water drained out of their boro paddy to raise another

---

[2] Public Distribution System which issues kerosene as cooking fuel to ration card holders.

rice crop in the lower field. Many, who were forced to give up boro cultivation altogether due to the high diesel cost, increased their area under mustard crop cultivation during the winter - when water can be pumped, or manually lifted for supplemental irrigation from ponds. In this new trend of replacing boro rice by rabi crops, irrigation cost relative to crop value has been a prime consideration for small farmers choosing between mustard, wheat and potato -mustard for example, fetches a better price and requires much less irrigation. The purchased diesel pump irrigation for rabi mustard may cost Rs. 200-250/bigha against Rs. 1,500/bigha for boro rice.

In our study village from Vidarbha, the system of rice intensification (SRI) was introduced a few years ago as a water-saving technology; but after trying it for a few seasons, farmers found its labor requirement in weeding to be daunting and SRI disappeared without trace. However, many small farmers did switch to the practice of dividing their farm in to small basins, roughly of 200 $m^{2,}$ at different heights for more efficient water, and diesel, use. In coastal Orissa's Purana Pradhan village, the soaring diesel price has induced farmers to convey water from the well-head to their fields either by flexible pipes or by masonry channels.

How the energy squeeze is heralding wholesale cropping pattern changes from diesel-intensive to diesel-saving crops was a striking feature in the Simra village of the Patna District, Bihar. In 1990, this was a wholly rice-wheat village with little crop diversification and that rarely moved away from this age-old rotation. Now, kharif paddy continues with or without irrigation; but during the rabi and summer, of its 300 ha, Simra has 150 ha under rain-fed masoor, 50 ha under lightly irrigated gram, 40 ha under wheat, and 75 and 20 ha, respectively, under intensively irrigated onion and coriander, the last fetching them the highest return per acre as well as per liter of diesel/kerosene. In the eastern UP village, Akataha (Deoria dist), farmers have switched from long duration to short duration paddy; and some of the irrigated paddy area has given way to diesel-saving groundnut and high-value potato crops.

The Gambler's Choice

Curiously, in several of our study areas, small farmers have responded to the diesel price squeeze by adopting even more diesel-intensive crops, mostly vegetables and sugarcane. In the eastern UP village, some parts of the wheat and paddy area have been replaced by highly profitable sugarcane cultivation. This reflects farmers moving from a low-input-low-output strategy to a high-input-high-income one to survive the rising cash-intensity of farming. This was most evident in the Abakpur Mobana village of the Mirzapur District in UP, where low-value rain-fed kharif crops are increasingly replaced by high-value, lightly irrigated vegetable and groundnut crops. Here, 90 % of the farm lands were under food crops (*jowar*, *bajra*, maize, gram, *tun*, and wheat) in 1990, but today, 80-90 % of the farm lands are under cash crops, high-value vegetables and diesel-efficient groundnut. The vegetables most widely grown here are chilli, tomato, brinjal, onion and potato.

The primary driver of the high-risk, capital intensive cropping strategy is the need to maximize the crop (and cash) per drop of diesel. In Purana Pradhan village in the Khurda District of coastal Orissa, Manas Satpathy computed that vegetables cost a lot more to cultivate in cash inputs than kharif or summer paddy, but on the other hand vegetables also offer greater cash returns (see Table 4). Some years ago, sugarcane was widely irrigated by diesel pumps, but now vegetables are the most important irrigated crop by diesel pumps in this village. The

Table 4. Costs and returns from paddy and vegetables, Khurda, Coastal Orissa (Satpathy).

	Cost of cultivation (Rs./acre)	Net return (Rs./acre)
Kharif paddy	3,500	2,500
Summer paddy	6,000	3,000
Vegetables	30,000	50,000

Source: Authors’ estimates based on farm survey

likely reason for this is because they yield the highest income per drop of diesel. Poorer farmers, whose main concern was food-grain security for the family, were cajoled into learning the new skills of vegetable cultivation and of marketing it to maximize their household income. A typical family in this scenario would intensively use their family labor (including men, women and children), on 1.5-2 acres of low-land and irrigate with either kerosene or electric pumps, whichever they have purchased. Co-operation among low-land vegetable growers here is of paramount importance. For example, if one of them chose to grow paddy, the water draining out of his field might ruin the near-by vegetable crop.

Another example of marginal farmers turning to risky high-value crops was found in the Simra village (Patna, Bihar)—(Chaube). Forced to give up winter wheat, sharecroppers and marginal farmers in the Simra village took to intensive cultivation of fully irrigated onion crops on small plots during the summer. This practice required a good deal of capital, but its higher cash returns justified the investment. Initially, intensive onion cultivation in the summer began as a strategy to beat the rising cost of diesel pump irrigation of wheat and other crops, but now, with the area under summer onion cultivation increasing to a quarter of the village’s farm land, the crop stimulated an increase in the purchases of diesel pumps. Because onion requires 13 irrigations to mature, and diesel pump owners levy a fixed charge of Rs. 3,000/bigha (Rs. 12,000/ha) for onion irrigation, the investment in a diesel pump is a very lucrative proposition. Simra’s onion revolution therefore, looked like a way to beat the energy squeeze.

Often, however, such desperate risky choices have ended up as sure ways of getting nothing out of something. This happened to Simra’s onion economy, too. After a few years of bumper returns, untimely summer rains ruined Simra’s onion crop in 2005 and 2006, leaving the small tenants in a huge debt trap. While some gutsy smallholders will still keep experimenting with onion, the chances are that most will steer clear of the high-value but risky onion crop, or choose a mix of onion and low-risk masoor to mitigate the risk of getting wiped out.

Similar was the experience in Birbhum. Struggling to survive, marginal farmers in Kaya and the surrounding villages took to marketing vegetable cultivation to replace the boro rice cultivation that they had to give up and at one stage, 25-30 % of Kaya’s farm lands were under vegetable cultivation. The switch proved highly remunerative for small farmers with large families who owned Chinese pumps. More recently however, vegetable prices have been dropping due to: a) glutting the market; b) the rising cost of road transport (a result of hikes in diesel prices). In 2006, Kaya produced a surfeit of cabbage that nobody was willing to lift, and many frustrated farmers had to plough it back into their fields. Kaya farmers are now coming full circle and experimenting with an admixture of two extreme crop groups: one, consisting of hardy, water-saving crops like oilseeds, wheat and pulses that offer low but risk-free returns; and the other, including crops like onion, coriander, black cumin that may offer better returns as cash crops, but are full of price and output risks (Banerjee).

Conclusion

Smallholder irrigation in India is under siege from an energy squeeze with three sides: (a) deterioration of farm power supply; (b) embargo on new electricity connections; and (c) an 8-fold increase in diesel prices since 1991. The Government of India's Accelerated Irrigation Benefits Program is investing tens of thousands of crores annually in surface irrigation, which is shrinking. But the real challenge Indian agriculture faces today is helping smallholder irrigators out of the energy squeeze. This paper summarized 15 village studies from different parts of India to explore the immiserizing impacts of the energy squeeze at the bottom of India's agrarian economy.

What could be done to counter the energy squeeze? Several ideas emerge from the struggles of farmers. For example, promoting fuel-efficient diesel/kerosene pumps of the Chinese variety can ease the cost-price squeeze or making available a PDS kerosene allocation to poor farmers, as in Kerala, too might help. The idea of providing subsidized diesel to farmers, as is done for trawler-operating fisher folk in certain states, is also gathering reception. Improving manual irrigation technologies and the better management of surface water bodies for gravity flow irrigation too can relieve the stress from the energy squeeze. Helping marginal farmers to own pumps can help relieve them from the monopoly of rents found in the prevailing pump irrigation prices.

However, all these must be treated as short- term patchwork. The real answer probably lies in improving the electricity supply to agriculture. A 2004 IWMI-Tata study in eastern UP showed that increasing diesel pump density helps the poor water buyers a little; but increasing electric pumps under a flat tariff can improve the net returns (from farming) of poor water buyers by 20-25 % , even if no yield gains are realized. Such a shift will have a huge impact in UP since 57 % of all food crop cultivators are water buyers here (Kishore et. al. 2004). This is true not only for eastern UP but for all of eastern India. However, realizing these gains for the poor requires a mindset-change. The invidious political economy of power subsidies that has emerged in India over the past three decades has encouraged state governments and power utilities to view agriculture as a pariah. This needs to change. If Indian agriculture is to thrive and our agrarian poor to prosper, it is critical that farm power supply is managed proactively. The challenge here is to manage farm power subsidies to acceptable levels in a manner that relieves the stranglehold of the energy squeeze on small- holder irrigation. Perhaps, Gujarat's *Jyotirgram Yojana* points at the way to go (Shah et al. 2007). Under this scheme, the Gujarat electricity board offers 8 hours daily of three-phase, full voltage power supply to tubewells along a pre-determined schedule. With some modification, this has the potential to contain the power subsidy to manageable levels and still beat the energy-squeeze with which smallholder irrigation in India is waging a losing battle today. By creating in eastern India a regime such as created by the *Jyotirgram Yojana* in Gujarat, the energy squeeze can be eased in a positive and proactive manner. Moreover, by giving marginal farmers priority in issuing new electricity connections for shallow and submersible tubewells, it is possible to generate equity benefits comparable to deep land reforms. Today, irrigation contributes as much to farm value creation as land; and by giving the agrarian poor preferential control over electricity connections and groundwater (the last frontier), a bold policy can give them the opportunity land reforms could not provide.

References

Kishore, A.; Mishra, K.N. 2004. "Cost of energy for irrigation and agrarian dynamism in Eastern Uttar Pradesh." Anand, India: IWMI-Tata Water Policy Program.

Banerjee, P. S. - village study from Murshidabad, West Bengal.

Chaube, R. - village case study of the Patna District in Bihar.

Chowdhury, S. D. - village study in Birbhum, West Bengal

Dasgupta, A. - village study in Barpeta District, Assam

Fujita, K.; Hossain, F. 1995 "Role of Groundwater Market in Agricultural Development and Income Distribution: A Case Study in a Northwest Bangladesh Village." *Developing Economies* XXXIII-4 (442-463), December.

Ishikawa, S .1967. Economic Development in Asian Perspective. Economic Research Series 8. Tokyo, Japan: Kinokuniya Bookstore Co.

Mardikar, S. - village study in Chandrapur, Vidarbha region, Maharashtra

Misra[a], U. - village study in the Hoshiarpur district, Punjab

Misra[b], U. - village study in Yamunanagar district, Haryana

Mukherji, A. 2006. Groundwater and agrarian change in West Bengal, India. Ph. D Thesis, Cambridge University, London, U.K.

Mukherji, A. 2005. "The spread and extent of irrigation rental market in India, 1976-77 to 1997-98: What does the National Sample Survey Data reveal?" IWMI-Tata Water Policy Research Highlight 7. Anand, India: IWMI-Tata Water Policy Program.

Narayanamoorthy, A. 2007. "Does groundwater irrigation reduce rural poverty? Evidence from Indian states." *Irrigation and Drainage* 56: 349-361.

Nayak, J. - village case study in Kalahandi, Orissa

Pant, N. 1984. "Community Tube Wells: An Organizational Alternative to Small Farmers' Irrigation." *Economic and Political Weekly* 19 (26): A59-A66; see also Ballabh, V (1989) Decline of a Novel Experiment: A Case Study of Group Irrigation Tubewells in Deoria District, presented at the at a workshop on "Efficiency and Equity in Groundwater Use and Management" held at the Institute of Rural Management Anand during Jan 30- Feb 1.

Pant, N. 2005. "Control and Access to Groundwater in UP." *Economic and Political Weekly* 40 (26):2672-2680, June 25-July 1, 2005

Raphael, J. - village study in Thrissur, Kerala

Satpathy, M. - village study from Khurda district, Orissa

Shah, T.; Verma, S. 2007. Real-time Co-management of Electricity and Groundwater: An Assessment of Gujarat's Pioneering Jyotirgram Scheme, Anand: IWMI-Tata Water Policy Program

Shah, T.; Ballabh, V. 1997. Water Markets in North Bihar: Six Village Studies in Muzaffarpur District. *Economic and Political Weekly* vol. XXXII, (52)

Shah, T. 1993. Groundwater Markets and Irrigation Development: Political Economy and Practical Policy. Bombay, India: Oxford University Press.

Shah, T.; Singh, O.P.; Mukherhi, A. 2006. "Some aspects of South Asia's groundwater irrigation economy: analyses from a survey in India, Pakistan, Nepal Terai and Bangladesh". *Hydrogeology Journal* 14(3): 286-309

Sharma, V. - village study in Ujjain, Madhya Pradesh

Singh, O.P. - village case study in Mirzapur, Uttar Pradesh.

Singh, Y. - village case study of Deoria, Eastern Uttar Pradesh.

SRIJAN - village study in Sehore district, Madhya Pradesh

Talati, J. - village study in Rajkot, Gujarat

Wilson, K. 2002. “Small cultivators in Bihar and ‘New’ Technology”. *Economic and Political Weekly* vol. XXXVII (13): 1229-1238,

Groundwater Externalities of Surface Irrigation Transfers Under National River Linking Project: Polavaram – Vijayawada Link

Bharat R. Sharma[1], K. V. G. K. Rao[2] and Sylvain Massuel[3]
[1] *International Water Management Institute, New Delhi, India*
[2] *Indwa Technologies, Hyderabad, India*
[3]*International Water Management Institute, Hyderabad, India*

Introduction

A large spatial variation exists in the availability of water resources in the different basins of India (Amarasinghe et al. 2005). Moreover, rainfall is mostly confined to the monsoon season and is unevenly distributed both in space and time. As a result, frequent droughts and floods continue to be annual features in most parts of the country. Realizing the need for providing water security in the water deficit areas, the Government of India formulated, in the year 1980, the National Perspectives for Water Resources Development, proposing therein the establishment of various long distance inter-basin water transfer links for transferring water from the water surplus basins of the country to the deficit areas/ basins. The plan has two main components: the Himalayan component and the peninsular component. The peninsular rivers development component envisages, as its first part, the diversion of surplus flows from the Mahanadi River to the Godavari system and then, the transfer of surplus waters from the Godavari system to the water short Krishna, Pennar and Cauvery basins. This would benefit the drought-prone areas of Andhra Pradesh, Karnataka, Maharashtra, Orissa and Tamil Nadu. The award given by the Godavari Water Disputes Tribunal (GWDT) stipulates, among other provisions, that 2,265 Mm^3 (80 TMC) of Godavari waters, from the Polavaram Project proposed by Andhra Pradesh, be diverted to the Krishna Basin above the Prakasam Barrage at Vijayawada. The Right Main Canal (Polavaram – Vijayawada Link, Indira Sagar Right Main Canal) will be 174 km long, and is envisaged to provide irrigation to a ‘culturable’ command area (CCA) of about 1.40 lakhs ha, in addition to the transfer of 2,265 Mm^3 of Godavari waters to Krishna (NWDA 1999).

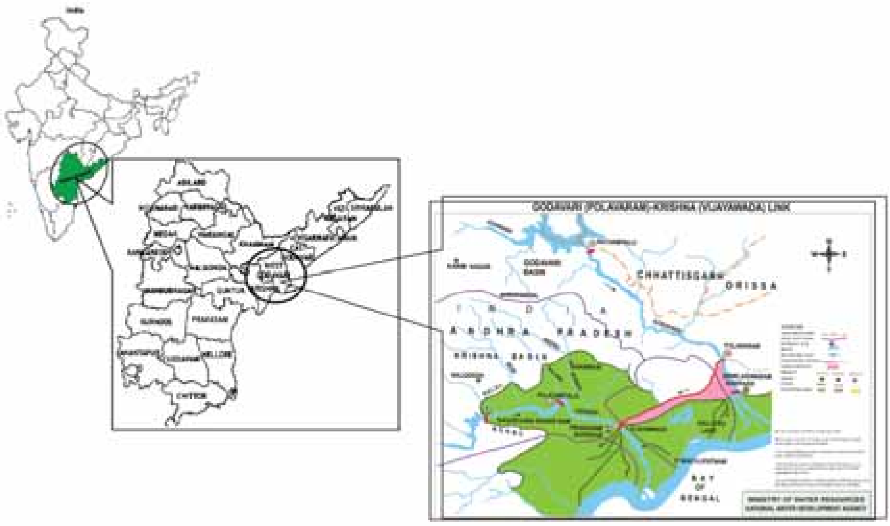
The provision of a canal distribution system and the application of surface water to such a large area, besides providing direct irrigation benefits, assist in the modification of the groundwater regime. Such groundwater externalities may generate positive results by providing additional recharge and improving the water table in a water-stressed area, but may also have a negative impact on the basins within the canal distribution system by creating waterlogging and increasing soil salinity in previously water congested pockets. These groundwater externalities are not adequately understood and factored into the project's feasibility reports. This paper has described: a) the proposed P-V Link's irrigation system; b) the geo-hydrological and agro-climatic soil conditions of the area; c) irrigation sources, cropping pattern and returns based on a primary farm survey; and d) the prognosis of the post project scenario of groundwater conditions.

Polavaram – Vijayawada (P-V) Link

The Polavaram Project (Figure 1) has been planned by the State of Andhra Pradesh as a multi-purpose project: a) to provide irrigation benefits to the upland areas; b) to provide a water supply to the industries in Visakhapatnam city, including the Steel Plant, for the generation of hydropower; and c) for the development of navigation and recreation facilities. The Polavaram Project envisages the construction of an earth-cum-rock filled dam that is 1,600 m long across the Godavari River at Polavaram, and about 42 km upstream of the Godavari Barrage at Dowlaiswaram. The dam will have a maximum height of 50 m in the deep course of the river and 38 m above average bed level. A 754 m long spillway on the right flank saddle is designed to regulate a flood discharge of 1.02 lakhs cumecs. A 560 m long and 58 m high masonry non-overflow dam accommodates the powerhouse and river sluices on the left flank.

The dam reservoir will create a live storage capacity of 2,130 Mm^3. The project envisages two canals, one on the left side and the other on the right side. The Left Main Canal will be

Figure 1. Location of Polavaram Project in Andhra Pradesh (INDIA).



208 km long and will provide irrigation to a CCA of 1.75 lakhs ha in the upland area of East Godavari and Visakhapatnam districts. The canal will also provide a water supply to Visakhapatnam. In addition, the Left Main Canal will also have provision for accommodating navigational requirements.

The Right Main Canal (Polavaram – Vijayawada, P-V Link) or Indira Sagar Right Main Canal (ISRMC))l is designed to carry 5,325 Mm^3 of water, of which 3,501 Mm^3 is to be transferred to the Krishna delta (2,265 Mm^3 as per GWDT award and an additional transfer of 1,236 Mm^3); 1,402 Mm^3 for providing irrigation to an extent of about 1.40 lakhs ha (CCA) en route; 162 Mm^3 for meeting the domestic and industrial needs of the command area; and with 260 Mm^3 to be the allowance for transmission losses. The canal irrigates areas in the Polavaram, Kovvur, Gopalapuram, Devarapalli, Nallajerla, Dwaraka Tirumala, Pedavegi, Denduluru, and Pedapadu *mandals* of the West Godavari District and Bapulapadu, Gannavaram, Vijayawada urban and rural *mandals* of the Krishna District (Table 1).

Table 1. Proposed command of Indira Sagar (Polavaram Project) Right Main Canal, Andhra Pradesh.

Sl. No.	Mandal, West Godavari District	Command Area, ha	Mandal, Krishna District	Command Area, ha
1.	Polavaram	3,188	Bapulapadu	4,713
2.	Gopalapuram	8,568	Nuzivedu	251
3.	Tallapudi	9,578	Gannavaram	12,436
4.	Devarapalli	7,377	Agiripalli	128
5.	Kovvur	9,047	Vijayawada (Rural)	4,366
6.	Dwaraka Tirumala	2,146	Vijayawada (Urban)	4,817
7.	Nallajerla	2,120	*Sub total*	*26,711*
8.	Chagallu	11,488		
9.	Tadepalligudem	15,236		
10.	Nidadavolu	10,717		
11.	Pedavegi	7,780		
12.	Unguturu	5,434		
13.	Denduluru	8,662		
14.	Bhimadolu	5,434		
15.	Pentapadu	172		
16.	Eluru	2,481		
17.	Pedapadu	3,313		
	Sub total	*112,741*		
	Total			139,452
	Total (Less 7.5% common lands)			128,993

Source: Office of ISRMC Circle, Eluru, Andhra Pradesh

P-V Link Command Area Features

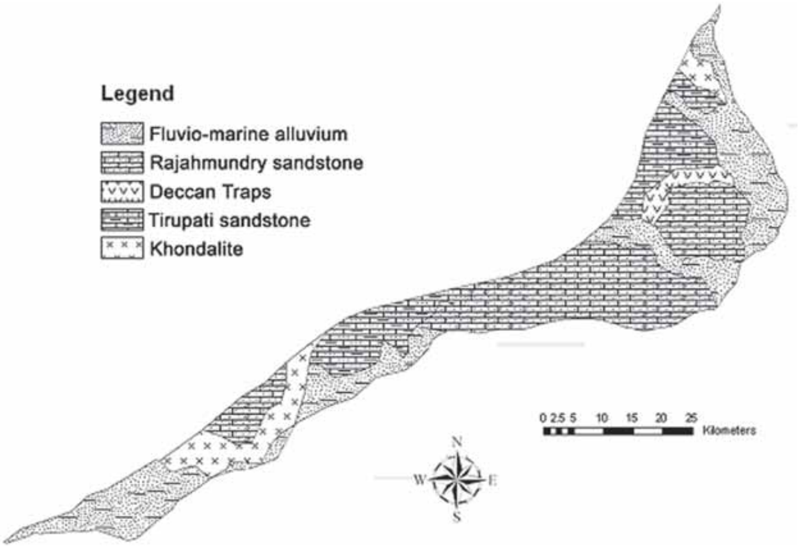
Climate and Topography

The Polavaram–Vijayawada (P-V) Link's canal command area falls under the Krishna-Godavari agro-climatic zone. The area has a hot and semi-arid to sub-humid tropical climate. The average annual rainfall is about 1,000 mm. About 70 % of the rainfall is received during the 4 months (June to September) of the southwest monsoon season, and 20 % in the northeast season (October to December). The temperature varies from about 44 ^{o}C (maximum) in May to about 22 ^{o}C (minimum) in December. The general topography of the area (through which the P-V Link is aligned with the en route command area) is mostly plain with a few local high mounds and sporadic hills. In general, the topsoil within the area is mainly of red earth, black cotton soils and river alluvium.

Geo-hydrological Conditions

A wide variety of the geological formations, ranging in age from the Achaeans to recent alluvium, occur in the West Godavari and Krishna districts (Figure 2). The geological formations in the P-V Link's canal command mainly belongs to Achaean group of rocks, which are represented by Khondalites, and Gondwanas, which in turn are represented by Chintalapudi, Gollapalli, Tirupathi and the younger Rajahmundry sandstones of the Mio-Pliocene age (GWD 1999; GWD 2003). The Khondalites are compact, hard and impervious in nature due to the absence of a primary porosity and permeability at certain places. With the development of secondary porosity, resulting from weathering, fracturing and re-joining, the Khondalites become groundwater repositories at selected pockets. The vertical extension of weathered/fractured zones varies widely from very shallow depths near the hill slopes to depths as great as 30 m in the valleys and topographic lows. The occurrence and movement of groundwater is

Figure 2. Geological map of P-V Link command.



controlled by the degree of interconnection between the secondary pores/ voids, which are developed through fracturing and weathering. In general, the Khondalite group of rocks has a poor groundwater yield. Groundwater occurs in these rocks under water table conditions, mainly in the weathered and fractured zones, and exploitable groundwater is found within the first 30 to 40 m of depth below ground level. The yields of the wells vary from 100 to 500 lpm. All the sandstone formations are continuous and provide as extensive aquifers but for intervening clays. In these sedimentary formations, groundwater is associated mainly with a primary porosity. The porosity and, hence, the storage capacity of these sandstones vary with the extent of shale and clays present in them. The Gollapalli sandstones, which have a high occurrence of shale, have poor groundwater potentials while the Chitalapudi and Tirupati sandstones possess good aquifers owing to their relatively more porous and permeable nature. Generally, the groundwater in these sedimentary formations occurs under semi-confined to confined conditions, and is exploited by means of dug-cum bore wells and tubewells of varying depths form 60 to 300 m below the ground, yielding 500 to 8,000 lpm. Rajamundry sandstones form the best aquifers in the district. The depth of wells constructed in these sandstones varies from 70 to 250 m below ground level and their yield ranges from 500 to 9,000 lpm.

Agriculture and Irrigation

Land Use

The net sown area in the *mandals* (through which the P-V Link right canal is aligned and proposed to irrigate parts of their lands) is about 55 % out of a geographical area of 4.9 lakhs ha in 2004-05 (CPO 2005). The area under forests is about 9.5 % with wastelands occupying about 67,000 ha and accounting for 14 % of the geographical area. Current fallow is about 5 %.

Groundwater Irrigation and Conditions

Presently, groundwater is the major source of irrigation for the proposed command of the P-V Link. Rain-fed farmers or the areas not receiving any irrigation were peculiarly absent from the study. All the farmers surveyed (excepting three) are irrigating their crops either under tubewells or canals (Table 2). As high as 85 % of the farmers depend solely on tubewell irrigation, while about 7 % of farmers depend on groundwater in conjunction with canal water. Thus, about 75.8 % of the area of the surveyed farmers is under tubewell irrigation and 11.6 % under the conjunctive use of groundwater and surface water. About 11 % of the farmers are using canal irrigation for 11.2 % of the irrigated area. The canal irrigation is from the Godavari delta irrigation system. The assessment of the NWDA had also showed groundwater as the major source of irrigation in the area.

As indicated by the source-wise irrigated area, groundwater irrigation is predominant in this area. Most of the area is under semi-consolidated formations, while the other geo-hydrological formations in the area are consolidated and unconsolidated (alluvium). Using the criteria of the ‘Ground Water Estimate Committee (GE)-1997’, the AP State Groundwater Department (GWD, 2006) has classified: four *mandals* as ‘Over Exploited’; four as ‘Critical’; and three as ‘Semi-Critical’ out of the 23 *mandals* of the West Godavari and Krishna districts, where the P-V command is located (Table 3).

Table 2. Mandal-wise sampled area under different sources of irrigation.

		Source of irrigation															
		Canal				Tubewell				Conjunctive use				Rain-fed			
Sl No	Mandal	Farmers	Kharif ha	Rabi ha	Annual Crops ha	Farmers	Kharif ha	Rabi ha	Annual Crops Ha	Farmers	Kharif ha	Rabi ha	Annual Crops ha	Farmers	Kharif ha	Rabi ha	Annual Crops ha
1.	Agiripally	-	-	-	-	10	17.4	-	-	1	4	4	-	-	-	-	-
2.	Devarapally	-	-	-	-	6	8.4	8.4	25.6	1	0.4	-	-	3	6.4	-	-
3.	Eluru	5	11.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.	Gannavaram	-	-	-	-	26	57.8	-	-	-	-	-	-	-	-	-	-
5.	Kovvur	-	-	-	-	-	-	-	-	7	30	30	16.4	-	-	-	-
6.	Nidadavolu	1	1	1	-	4	1.2	1.2	14	-	-	-	-	-	-	-	-
7.	Nuzivedu	-	-	-	-	18	26.4	2.4	4.8	-	-	-	-	-	-	-	-
8.	Pedavegi	-	-	-	-	16	25.6	25.6	48.8	-	-	-	-	-	-	-	-
9.	Polavaram	-	-	-	-	11	9.4	-	-	2	2.8	-	-	-	-	-	-
10.	Tadepallygudum	5	18	18	-	17	30	25.6	10.8	-	-	-	-	-	-	-	-
11.	Tallapudi	-	-	-	-	15	27.8	-	4	-	-	-	-	-	-	-	-
12.	Unguturu	6	20.8	20.8	-	9	23.2	21.6	8	-	-	-	-	-	-	-	-
13.	Vijayawada	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-
	Total	17	51.4	39.8	0	132	227.2	84.8	122	11	37.2	34	16.4	3	6.4	0	0
	Percentage	11	16	25	0	85	71	53	88	7	12	21	12	2	2	0	0
	Cropping intensity	177				124				163				100			

Source: Authors' estimation based on the primary survey

Table 3. Groundwater assessment of West Godavari and Krishna districts.

Serial	Mandal	Groundwater availability ha-m			Groundwater utilization ha-m			Groundwater balance ha-m			Stage of development (%)			Category		
no.		C	NC	Total	C	NC	Total	C	NC	Total	C	NC	Total	C	NC	Total
	West Godavari District															
1.	Polavaram	0	3,383	3,383	0	830	830	0	2,553	2,553	NA	25	25	NA	Safe	Safe
2.	Tallapudi	0	2,038	2,038	0	1,699	1,699	0	399	399	NA	83	83	NA	SC	SC
3.	Gopalapuram	0	4,393	4,393	0	5,357	5,357	0	-964	-964	NA	122	122	NA	OE	OE
4.	Dwarakatirumala	0	3,285	3,285	0	2,959	2,959	0	326	326	NA	90	90	NA	Cri	Cri
5.	Nallajarla	0	3,643	3,643	0	3,451	3,451	0	192	192	NA	95	95	NA	Cri	Cri
6.	Devarapalli	0	5,314	5,314	0	5,283	5,283	0	31	31	NA	99	99	NA	Cri	Cri
7.	Chagallu	0	2,040	2,040	0	1,476	1,476	0	564	564	NA	72	72	NA	SC	SC
8.	Kovvuru	0	1,959	1,959	0	2,437	2,437	0	-478	-478	NA	124	124	NA	OE	OE
9.	Nidadavolu	0	2,868	2,868	0	3,298	3,298	0	-430	-430	NA	115	115	NA	OE	OE
10.	Tadepalligudem	1,022	2,304	3,326	116	1,944	2,060	906	361	1,267	11	84	62	Safe	SC	Safe
11.	Unguturu	1,807	1,883	3,690	96	974	1,069	1,711	909	2,621	5	52	29	Safe	Safe	Safe
12.	Bhimadolu	2,633	1,421	4,054	15	946	962	2,618	474	3,093	1	67	24	Safe	Safe	Safe
13.	Pedavegi	0	4,349	4,349	0	5,745	5,745	0	-1,396	-1,396	NA	132	132	NA	OE	OE
14.	Pedapadu	2,898	840	3,737	15	391	405	2,883	449	3,332	1	47	11	Safe	Safe	Safe
15.	Eluru	3,323	177	3,500	77	241	318	3,246	-64	3,182	2	136	9	Safe	OE	Safe
16.	Denduluru	2,401	1,949	4,351	0	2,763	2,763	2,401	-814	1,587	0	142	64	Safe	OE	Safe
17.	Pentapadu	2,890	0	2,890	0	0	0	2,890	0	2,890	0	NA	0	Safe	NA	Safe
	District	75,861	73,050	148,910	2,483	68,761	71,244	73,378	4,288	77,666	3	94	48	Safe	Cri	Safe
	Krishna District															
18.	Vijayawada (Rural)	2,943	948	3,891	690	826	1,516	2,253	122	2,376	23	87	39	Safe	SC	Safe
19.	Vijayawada (Urban)	1,676	0	1,676	242	61	304	1,434	-61	1,372	14	NA	18	Safe	NA	Safe
20.	Gannavaram	1,694	1,186	2,880	160	526	686	1,534	660	2,194	9	44	24	Safe	Safe	Safe
21.	Agiripalli	0	2,475	2,475	11	1,148	1,159	-11	1,328	1,316	NA	46	47	NA	Safe	Safe
22.	Nuzvid	0	3,211	3,211	0	2,658	2,658	0	553	553	NA	83	83	NA	SC	SC
23.	Bapulapadu	6,865	1,895	8,760	238	1,639	1,877	6,626	256	6,882	3	86	21	Safe	SC	Safe
	District	151,679	53,153	204,832	21,574	28,394	49,968	130,105	24,759	154,864	14	53	24	Safe	Safe	Safe

The piezometers show that the depth of groundwater piezometric levels range from 4.65 to 43.5 m, with an average of 22.5 m during the pre-monsoon period. During the post-monsoon season the range is 1.01 to 37.39 m, with an average of 16.5 m. Waterlogging conditions also prevail in certain *mandals* with 40 % of the observation wells showing post-monsoon levels of less than 2.0 m.

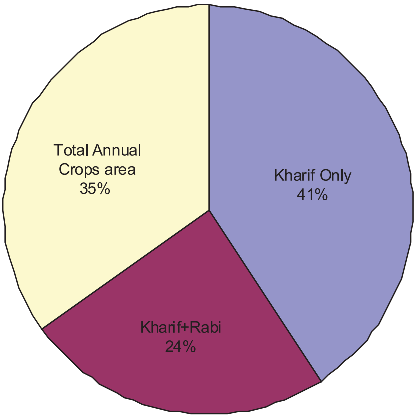
Cropping Pattern

As a part of this study, a survey on the positive and negative externalities of groundwater use and expected benefits from the proposed link has been conducted among 155 farmers spread across the proposed command area of the P-V link through a questionnaire by Sakti, a Hyderabad-based NGO with field offices in the project area. The cropping pattern as reported by District Handbooks of Statistics (CPO 2005) and deduced from the Farm Survey is somewhat similar.

The availability of water on demand and precision in its application encourage farmers in crop diversification and in the adoption of high-value crops. As such, in tubewell irrigated areas, a wide variety of crops are cultivated. Annual crops like tobacco, sugarcane, coconut, oil palm and mango gardens occupy about 35 % of the area of the surveyed farmers (Figure 3). The remaining 65 % of the irrigated area is under various kharif crops. Due to the limited water availability, rabi crops are grown only in about 24 % of the area covered under kharif crops. Thus the cropping intensity under the canal-irrigated area is 177 %, under tubewell it is about 124 %, and under rain-fed conditions only kharif crops are grown (Table 2). Sugarcane (12.2 %) and tobacco (6 %) are the major annual crops in the surveyed area (Table 4).

About 88 % of the area under annual crops is under tubewell irrigation and the remaining 12 % under conjunctive use. The area under canal irrigation is under field crops only. This confirms the earlier assumption that an assured and controlled water supply is a pre-requisite for crop diversification and the adoption of high-value crops under the traditional cropping systems. As such, the additional area proposed to be brought under surface irrigation with

Figure 3. Cropped area under tubewell irrigation – P-V Link.



Source: Authors' estimates based on primary survey

Table 4. P-V Link kharif cropping pattern for the surveyed farmers.

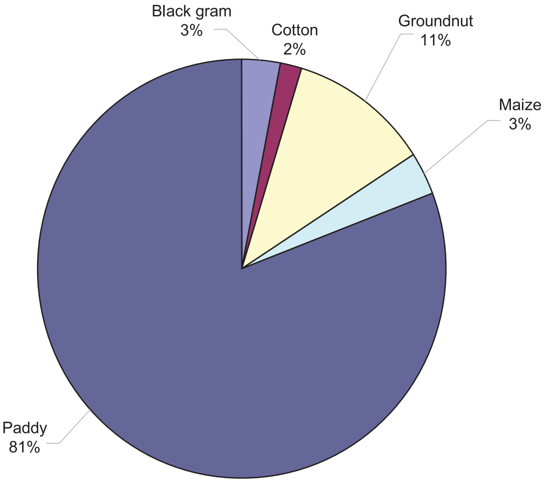
Crop	Total cultivated area ha	Canal	Conjunctive use	Rain-fed	Tubewell	Area, ha	% to Total cultivated area
Sugarcane		-	16.4		40	56.4	12.2
Coconut		-			40.8	40.8	8.9
Mango		-			6	6	1.3
Palm oil		-			8	8	1.7
Tobacco		-			27.2	27.2	5.9
Total annual crops	461		16.4		122	138	
Black gram		-			7	7	1.5
Cotton		-			3.6	3.6	0.8
Groundnut		-			25.6	25.6	5.6
Maize		-	0.8		7.2	8	1.7
Paddy		51.4	36.8	6.4	183.6	278.2	60.3
Kharif area		51.4	37.6	6.4	227	322	

Source: Authors' estimation based on the primary survey

canal irrigation shall be mainly under traditional grain crops and, it is only through enhanced supplies and coverage of groundwater that much of the additional areas under crop diversification, dairy and other remunerative enterprises are likely to develop.

Canal irrigation promotes the wide-scale adoption of paddy in Andhra Pradesh. Paddy in kharif followed by paddy in rabi is the cropping pattern under canal irrigation, as in the rest of the Godawari delta irrigation system. Even under tubewell irrigation, paddy is the predominant crop in the kharif season (Figure 4), and is cultivated in about 81 % of the area followed by

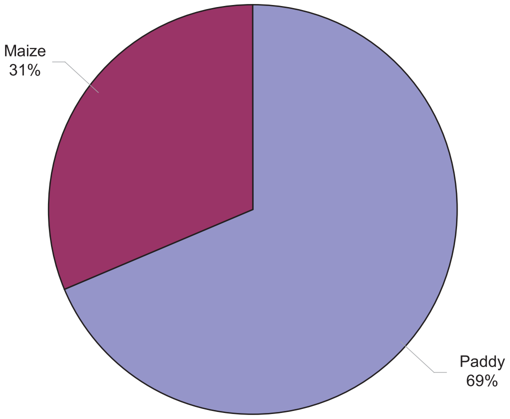
Figure 4. Kharif cropping under tubewell irrigation – P.V. Link.



Source: Authors' estimation based on the primary survey

groundnut, maize, black gram and cotton. In the rabi season mainly two crops are grown; paddy in about 69 % and maize in the rest of the irrigated area (Figure 5). Most of the rabi paddy is grown in Tadepallygudem and Unguturu *mandals,* which are close to the delta irrigation system. Only about 34 % of the total kharif area is also under rabi cropping. During a field visit to the command, the farmers indicated that tubewell water is adequate to supplement rainfall for the kharif crops, but it is not enough to irrigate an additional rabi crop.

Figure 5. Rabi crops area under tubewell irrigation – P.V. Link



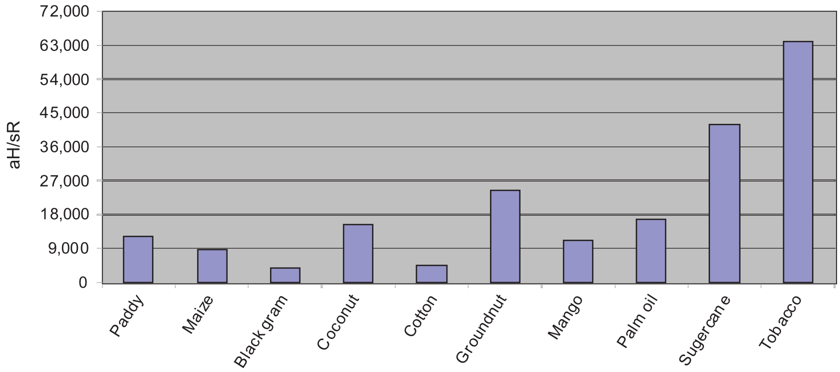
Source: Authors' estimation based on the primary survey

Crop Yields and Net Returns

The average paddy yields are similar under canal and tubewell irrigation (5.0 t/ha) during the kharif season. However, the yields are higher under canal irrigation at 7.2 t/ha in the rabi season. For the large number of tubewell-owning farmers, insufficient groundwater supplies and little support from rainfall constrain their paddy yields to 5.9 t/ha during the rabi season. However, with conjunctive use irrigation in the rabi season paddy yields improve to 6.9 t/ha. The paddy yields under rain-fed irrigation are the lowest at 3.5 t/ha. The data points to an urgent need for the replacement of water-intensive paddy with less water-intensive but more remunerative rabi crops like black gram, groundnut and maize. In the water-stressed Krishna delta area, black gram is the major crop during the rabi season, raised with only one/two irrigations and generating high financial returns.

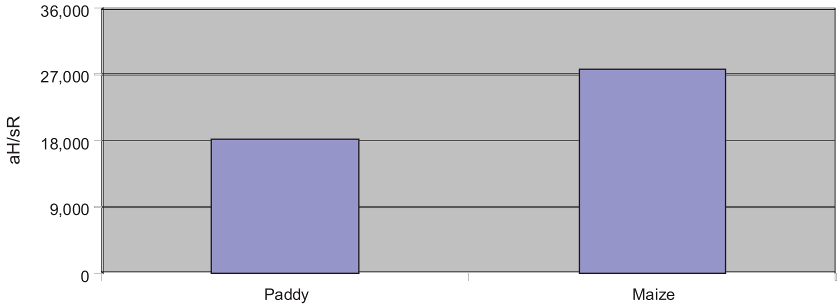
Tobacco gives the highest average net return with about Rs. 63,916/ha, followed by sugarcane with Rs 41,859/ha (Figure 6a). Among the seasonal crops, groundnut yields an average net return of Rs. 24,496/ha and maize Rs. 8,800/ha in the kharif (Figure 6a) and Rs. 27,803/ha in the rabi season (Figure 6b). The average net return of paddy, the largest cultivated crop, is about Rs. 12,158/ha. When both seasons are considered, the net return for paddy under tubewell irrigation, is about Rs. 30,378/ha, and under canal irrigation it is Rs. 40,728/ha (Figure 7). Even though the paddy yields are only slightly different under the canal and tubewell irrigation, the wide variation in the net returns is due to higher tubewell

Figure 6a. Average kharif net returns for different crops.



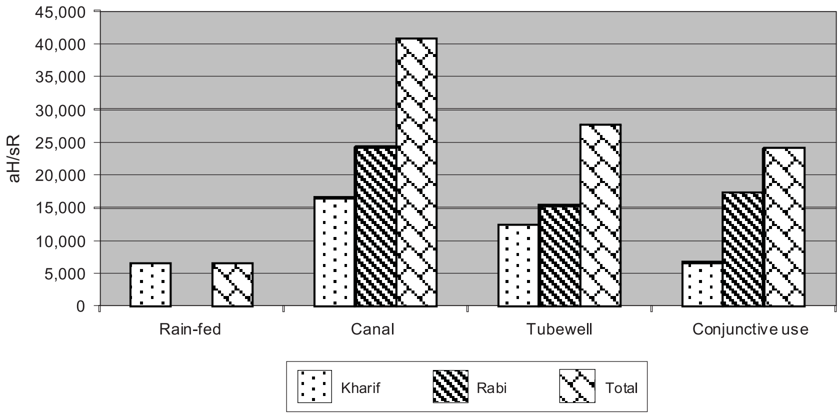
Source: Authors' estimates based on the primary survey

Figure 6b. Average rabi net returns for different crops.



Source: Authors' estimates based on the primary survey

Figure 7. Average net returns with paddy under different irrigation sources.



Source: Authors' estimates based on the primary survey maintenance costs. Groundnut in the kharif, followed by maize, may give the highest returns of about Rs. 52,299/ha/yr among the seasonal crops. Simple economic sense also points out that paddy crop should not be cultivated only with tubewell water during the rabi season, despite the fact that the state provides free power to the farmers for pumping groundwater. Maize has higher net returns and lower water requirements even under the existing situations.

Groundwater Model Studies: Prognosis of Change

The introduction of canal irrigation is known to enhance the recharge of groundwater, which can be used for irrigation through conjunctive use; and also to cause waterlogging conditions and soil salinity in poor quality groundwater regions (Sondhi and Kaushal 2006). A groundwater model study has been conducted using MODFLOW for predicting the groundwater externalities arising from the irrigation in the P-V Link's command. Satellite images from Google Earth and Digital Elevation Models have been used in demarcating the command boundaries, land use and topography. The information on lithology and groundwater depths and quality collected by the AP State Groundwater Department has been used in the model study. The following hydrodynamic parameters have been used (see Table 5).

Table 5. Common hydrodynamic values of different geological formations.

Geological formation*	Permeability (K m.s^{-1})	Storagitivity (%)
Alluvium	10-4 to 10-7	8 to 9
Sandstone	10-3 to 10-6	2 to 15
Fractured basalt	10-2 to 10-5	8 to 10
Fractured granite	10-2 to 10-7	0.1 to 2

Note: *compilation of various sources

The hydrological year is divided into two main trends in groundwater levels: a) a trend of rising water levels during the monsoon season (recharge); and b) a trend of declining water levels during the dry season. To characterize the two different states of the water table, the ends of each season are selected as initial levels (May and November) for each model, respectively.

Calibration is performed only on the MR1 model (rabi season model before P-V Link canal), where the direct groundwater recharge from rainfall does not occur. This minimizes the uncertainty of fixed variables and leads to an easier calibration of aquifer characteristics—only permeability and specific storage parameters are fine tuned. The discrepancies between simulated and observed water table levels are minimized by optimization of an objective function (Root Mean Square), based on 14 piezometric control points selected for the quality of the measurement and their representativeness. A good fitting is obtained with observed water level values. Root Mean Square Error (RMSE) is 3.79 m, which remains quite satisfactory for such a large zone with a complex geological pattern. For validation, the

MK1 (kharif season model before P-V Link canal) model is run applying the direct groundwater recharge from rainfall, all other things being equal. The MK1 simulation flow efficiency is calculated in reference to the piezometric values of the kharif season. The fitting between observed and calculated heads remains good (RMSE = 4.2m). Therefore, the MK1 model confirms the reliability of the MR1 model calibration.

According to the groundwater model in a steady state, the PV-link canal has a significant influence on the groundwater budget: (i) directly by the canal seepage; (ii) indirectly by the irrigation return flow; and (iii) additional groundwater draft due to extension of the command area. Groundwater recharge increases by 28 % due to the supplementary irrigation return flow in the new ISRMC command area. Annual estimated recharge from ISRMC seepage is 130 mm/yr, around 183 Mm^3/yr, which is consistent with the estimations of designed total transmission losses of 260 Mm^3/yr. The annual (rabi + kharif) balance between the situations before and after ISRMC shows a net increase in recharge of 73 mm. Assuming an average aquifer effective porosity of 4 % can explain a water table rise of 1.83 m.

Assuming the addition of 73 mm on water availability, all other things being equal, it appears that the groundwater development status of the five *mandal* categories will change with the additional recharge: ‘Over exploited’ becomes ‘critical’ for two *mandals* (Kovvuru and Nidadavolu); ‘critical’ becomes ‘semi-critical’ for one *mandal* (Dwarakatirumala); and ‘semi-critical’ becomes ‘safe’ for two *mandals* (Chagallu and Tallapudi).

According to the simulations, the potential area of waterlogging (<2m bgl) could increase by 16 % in the rabi and by 19 % in the kharif season, and cover 342 km^2 and 390 km^2 ,respectively, out of the 1,582 km^2 of the inter-canal area. The expansion occurs mainly in the vicinity of the P-V Link canal and, particularly, in the Gannavaram Mandal. The MODFLOW cannot simulate perched local water tables, as such, the presented estimates could underestimate the extent of waterlogged areas.

Expected Crop Production Benefits from P-V Link

The National Water Development Agency in its P-V Link evaluation study has assessed that currently approximately 96,785 ha is under irrigated crops and another 4,032 ha area is under rain-fed crops (Table 4). An area of about 35,953 ha needs to be developed before surface irrigation is introduced. At present the cropping intensity in tubewell and canal irrigated area of the contemplated command area is about 124 %. The farmers’ survey results on the net benefits have been used to estimate the current agricultural net returns and the expected benefits in the future after the commissioning of the P-V link project. Annually, the net returns from groundwater dependent agriculture in the proposed command is about Rs. 162 crores (INR 1.62 billion), which is threatened due to a diminishing resource and declining groundwater levels. After the commissioning of the P-V Link, not only the groundwater irrigated area will be sustainable but also the remaining rain-fed area that will come under irrigation. Overall, the cropping intensity is expected to increase to 150 %. The projected estimates show that the total current benefits of about Rs. 16,872 lakhs/year are likely to increase to Rs. 27,853 lakhs/year—an increase of about Rs. 11,000 lakhs/year (due to enhanced crop production from more area under irrigation and increased cropping intensity, (see Table 6).

Table 6. Projected net returns in P-V Link command.

Crop	NWDA assessed area under crops			Irrigated Area			Unirrigated Area			Current net returns (Rs. in lakhs)	Projected net returns after P-V Link (Rs.in lakhs)
	Irrigated area ha	Unirrigated area, ha	Total ha	Yield t/ha	Net Returns, Rs/ha	Total Net Returns, Rs in lakhs	Yield, t/ha	Net Returns, Rs/ha	Total Net Returns Rs in lakhs		
Rice	60,672	713	61,385	5.0	12,158	7,377	1.69	7,473	53	7,430	7,463
Black Gram	6,150	1,465	7,615	0.6	9,995	615	0.4	7,465	109	724	761
Maize	2,553	201	2,754	4.8	8,800	225	1.87	3,153.8	6	231	242
Chillies/Cotton	2,972	25	2,997	1.0	11,145	331	0.5	5,676.2	1	333	334
Groundnut	6,786	810	7,596	3.1	24,496	1,662	1.58	7,299.4	59	1,721	1,861
Tobacco	1,728	0	1,728	1.9	63,916	1,104		0	-	1,104	1,104
Sugarcane	9,258	0	9,258	86.7	41,859	3,875		0	-	3,875	3,875
Fruits/Mango	0	3,945	3,945	0	0	-	25.8	10,954	432	432	432
Palm oil, Coconut	6,339	0	6,339	-	16,103	1,021		0	-	1,021	1,021
Sub-total	96,458	7,159	103,617		16,805	16,210		9,247	662	16,872	17,094
Unirrigated area to be developed		35,953	35,953								5,931
Total expected net returns											23,025
Total expected net returns with cropping intensity of 150 %											27,853

Assumptions:

(1) Cropping intensity shall increase from the current level of 124 % to 150 % after the project

(2) The existing unirrigated area after the project will have a similar cropping pattern as that of the current irrigated area

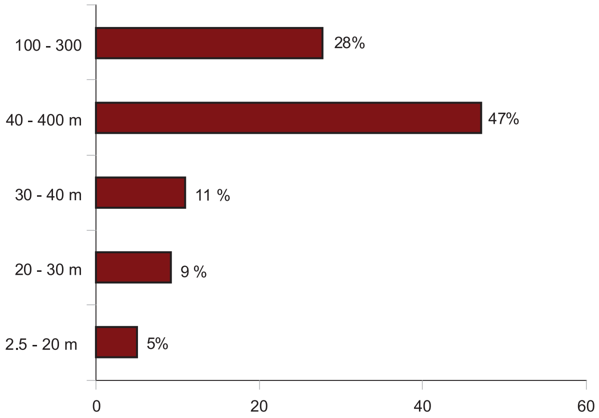
Source: Authors' estimation based on the primary survey

Sustainability Issues of the P-V Link Command

Groundwater Irrigation

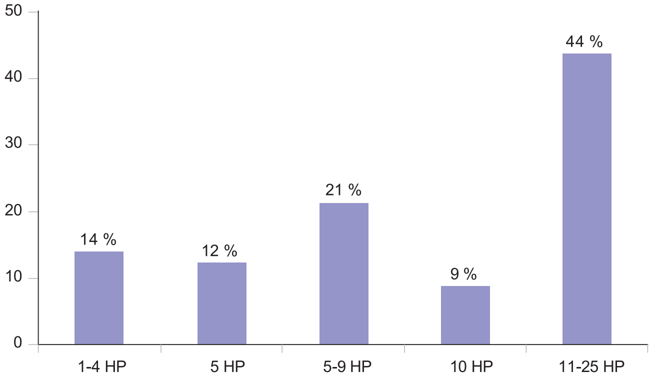
Groundwater irrigation has been reported to be beneficial in terms of higher productivity and cropping intensity, as compared to rain-fed agriculture. However, groundwater irrigation through tubewells in the consolidated and semi-consolidated formations of the area is already threatened with declining groundwater levels and over-exploitation. More than 75 % of tubewells are deeper than 40 m (Figure 8), and 28 % of them are deeper than 100 m. The deep tubewells have necessitated the installation of higher capacity pump sets. More than 53 % of the pump sets used are of a capacity as high as 10 HP or more (Figure 9), sometimes even as high as 25 HP. The cost of tubewell installation and the cost of maintenance are also very high and on average costs Rs. 1,46,000 and Rs. 3,000/ha, respectively (Table 7).

Figure 8. Depths of tubewells in the P-V Link area.



Source: Authors' estimation based on the primary survey

Figure 9. Tubewell pumpset capacity in P-V Link area.



Source: Authors' estimation based on the primary survey

Table 7. Cost of tubewell construction and pump-set and maintenance cost per ha.

Tubewell + Pump-set Cost Rs.	No. of tubewells	Tubewell maintenance cost Rs. / ha	No. of tubewells
25,000 - 50,000	10	1,000-2,000	22
50,000 - 100,000	31	2,000-3,000	69
100,000 - 150,000	41	3,000-4,000	16
150,000 - 200,000	22	4,000-5,000	17
200,000 - 250,000	15	5,000-9,000	7
>250,000	12	Cost not known	4
Cost not known	4	Total tubewells	135
Total tubewells	135	Average	Rs. 3,000/ha
Average cost	Rs. 1,46,000		

Source: Authors' estimation based on the primary survey

The cost of tubewell installation and pumpsets of 67 % of the 135 tubewells in the area is more than Rs. 100,000 for farmers. Presently, the power supply is fully subsidized and the farmers are not paying any electricity charges in Andhra Pradesh. However, the state has to reimburse these costs to the APTRANSCO (State Power Supply Agency). In calculating the net returns only the cost of tubewell maintenance has been considered. If the interest on capital cost and the opportunity cost of power supply are considered, the viability of tubewell irrigation from such deep groundwater bodies may become decline and ultimately become unviable. Recharges to the groundwater body from the surface water to be brought into the area through the P-V Link are likely to reduce the stress on groundwater and is likely to become less costly.

Waterlogging and Soil Salinity

Even though 51 farmers (33 %) reported some sort of soil salinity problem and of having to adopt coping measures such as gypsum application, FYM application etc. (Table 8), the problem of soil salinity is not serious, as indicated by the crop yields - the paddy yields from the supposedly soil salinity affected areas are as good as normal soils. However, due to the presence of hard-rocks and clayey layers at shallow depths, waterlogging problems may occur in the command, as happened in the neighboring Nagarjuna Sagar Left Canal command, where about 7.0 % of the command area is reported to be suffering from groundwater levels less than 2.0 m below ground level. Model studies have made a prognosis of the extent and location of the expected waterlogging problem in the proposed command.

Table 8. Cost of coping measures for soil salinity and waterlogging.

Soil Salinity (SS) Coping Measures	Average Cost, Rs/ ha	Range, Rs/ha
Scrapping of salts	543	400 – 1,000
Gypsum application	739	250 – 2,500
FYM application	1,045	500 – 2,800
Additional expenditure due to soil salinity	1,519	250 – 3,475
Additional expenditure due to waterlogging	500	500

Recommended Agriculture Strategy under the P-V Link

The strategy for realizing the benefits of bringing canal irrigation under the P-V Link to this water-stressed and predominantly groundwater irrigated area has to focus on improving agricultural production, sustaining the infrastructure (tubewells, electricity connections, micro-irrigation systems, processing facilities, etc.) that is already built and safeguarding the livelihoods of farmers resident in these areas. The following points need attention.

- In the sampled area, 135 out of the 155 farmers own a tubewell, and incur heavy investments on tubewell construction and pump sets. Even after the introduction of canal irrigation, conjunctive use of surface and ground waters needs to be promoted to provide better irrigation facilities to the crops, to make use of the farmer-owned infrastructure and to prevent waterlogging and consequent soil salinity problems.

- When the seasonal and annual crops are considered, about 40 % of the irrigated area is under crops other than paddy. About 12 % of the area is under horticulture and many of the horticulture farms have been installed with micro-irrigation systems. Similarly, tobacco cultivators in the area have established post crop processing facilities for drying, packing and transporting tobacco to factories. Necessary policies need to be in place to promote the utilization of these facilities and further expand this cropping system to reduce the dependency on the paddy crop—a highly water-intensive grain crop.

- Groundnut in the kharif followed by maize in the rabi, seems to be a good combination for less water use and high net returns. Similarly, the project area has a large area under annual crops and plantations, but yield levels of these enterprises are sub-optimal and need to be significantly improved to realize higher values per unit of water utilized.

- Introduction of surface irrigation systems in the sub-basin is likely to improve the groundwater regime and, yet, may not be sufficient enough to sustainably meet the current and future water requirements. The conjunctive management of surface and groundwater resources and a scientific demand management through optimization of cropping systems have the potential to effectively harness the benefits of this river-linking initiative.

- About 16 % of the proposed command is likely to witness waterlogging, especially in the Gannavaram block. And if appropriate remedial measures, such as proper planning of groundwater use in the affected and adjoining areas, are not put in place, this will become a serious negative externality of the project. However, the worst affected areas can be put under paddy-paddy crop rotation for higher economic benefits.

- Since the proposed command area is already agriculturally well developed, the introduction of canal irrigation should aim at sustaining the agriculture in the water-stressed area without leading to major changes in the cropping pattern, and ensuring better livelihoods.

References

Amarasinghe, U.A.; Sharma, B.R.; Aloysius, N.; Scott, C.; Smakhtin, V.; de Fraiture, C. 2005. *Spatial variation of water supply and demand across river basins of India.* Research Report 83. Colombo, Sri Lanka: International Water Management Institute (IWMI).

CPO, 2005. Handbook of Statistics. West Godavari District, Eluru, supplied by Directorate of Economics and Statistics, Hyderabad.

CPO, 2005. Handbook of Statistics. Krishna District, Machilipatnam, supplied by Directorate of Economics and Statistics, Hyderabad.

GWD (Ground Water Department). 2006. Groundwater resource 2004-05. Volumes 1 & 2. Groundwater Department, Government of Andhra Pradesh, Hyderabad.

GWD (Ground Water Department). 2003. Groundwater Year Books 200-01 & 2001–02. West Godavari District. Groundwater Department, Government of Andhra Pradesh, Hyderabad.

GWD (Ground Water Department). 1999. Groundwater resources and prospects of Krishna District. In *Swarnandhra* Pradesh by DRDA. Groundwater Department, Government of Andhra Pradesh, Hyderabad.

National Water Development Agency. 1999. Feasibility Report of Polavaram- Vijayawada Link. National Water Development Agency (www.nwda.gov.in), Ministry of Water Resources, Government of India, New Delhi.

Sondhi, S.K; Kaushal, M.P. 2006. Simulation modeling and optimization studies for groundwater basins of northwest India: Case studies and policy implications. In *Groundwater Research and Management: Integrating Science into Management Decisions,* eds. Bharat R. Sharma, K.G. Villholth, K.D. Sharma Colombo, Sri Lanka: International Water Management Institute (IWMI). pp 147-168.

Rainwater Harvesting in the Water-scarce Regions of India: Potential and Pitfalls

M. Dinesh Kumar[1]*, Ankit Patel*[1] *and O.P. Singh*[2]
[1] *IWMI-TATA Water Policy Program, Hyderabad, India*
[2] *Benaras Hindu University, Varenasi, India*

Introduction

India has a long tradition of water harvesting. Many of the traditional water harvesting systems have either fallen to disuse due to a variety of physical, social, economic, cultural and political factors that have caused their deterioration, and due to the decline of institutions that have nurtured them (Agarwal and Narain 1997), or have lost their relevance in the modern day context due to their inability to meet the desires of communities. While the first dimension of the decline in water harvesting tradition has been well researched and documented, the second dimension is much less understood and appreciated. The lack of willingness to appreciate the fact that different periods in history are marked by the genesis, rise and fall of new water harvesting traditions, is also very clear.

In the history of India's water sector, the past two decades are characterized by a boom in water harvesting. They are markedly different from the years of traditional harvesting in two ways; first, in terms of the context; and second, in terms of the purpose. As regards the context, the two decades are able to use recent advancements in soil, geosciences and hydro-sciences; and modern day techniques and technologies in survey and investigation, earth moving and construction; and management tools such as hydrological and hydraulic modeling. While the traditional years of harvesting represented the best engineering feats of those times, in terms of the water technology used for water harnessing and distribution (Agarwal and Narain 1997), and the volume of water handled, the modern water harvesting systems are at best miniature versions of the large water resource systems that used advances in civil engineering and hydrology. As regards the purpose, modern water harvesting systems are employed as resource management solutions, and not as resource development solutions. For instance, many water harvesting structures were built for improving aquifer storages and groundwater quality.

The limited Indian research on rainwater harvesting (RWH)/artificial recharge so far had focused on the engineering performance of individual structures (see Muralidharan and Athawale 1998). While a lot of anecdotal evidence on the social and economic gains is available, there is little understanding, based on empirical work, of: 1) the impacts of water harvesting activities on local hydrological regimes in terms of net water gain; 2) basin level impacts on the overall basin water balance; and 3) economic imperatives from a long-term perspective. Of late, researchers had raised questions of the possible unintended impacts of water harvesting (see Bachelor et al. 2002), and its economics (see Kumar 2004). One of the reasons for little or lack of empirical research on the hydrological and economic aspects of water harvesting systems is the lack of ability to generate accurate scientific data on various parameters, mostly hydraulic, hydrological and meteorological, governing the performance and impact of water harvesting. The problem mainly stems from the fact that these systems are very micro in nature, thereby making it difficult to obtain data on the variables from conventional sources. The analysis of water harvesting systems also misses the influence of the 'scale factor'.

Objectives of the Paper and Approach

The paper begins with the basic premise that scale considerations are important in analyzing the impact of water harvesting, i.e., one has to move from the local watershed level analysis to the river basin level analysis, and that basin level impacts are not always aggregates of local impacts. The paper first discusses the critical issues in rainwater harvesting from micro and macro perspectives. The macro level analysis is strengthened by primary data on hydrological variables collected from two small river basins. It then goes on to make practical suggestions for effective rainwater harvesting.

The paper would try and achieve the following: 1)] present the major typologies in water harvesting in India; 2) discuss the physical—hydrological and meteorological— and socioeconomic and purely economic considerations that need to be involved in decision - making with regard to water harvesting investments or analyzing the impact of RWH systems, and how these considerations limit the scope of water harvesting; and 3) make practical suggestions for improving the effectiveness of rainwater harvesting.

Critical Issues in Rainwater Harvesting

One of the most important underlying values in rainwater harvesting is that it is a benign technology (Bachelor et al. 2002) and cannot create undesirable consequences. Water harvesting initiatives are driven by firm beliefs and assumptions, some of which are: 1) that there is a huge amount of monsoon flow, which remains un-captured and eventually ends up in the natural sinks, especially seas and oceans, supported by the national level aggregates of macro hydrology; 2) that local water needs are too small and as such exogenous water is not needed; 3) that local water harvesting systems are always small and, therefore, are cost-effective; 4) since the economic, social and environmental values of water are very high in regions hit by water shortages, water harvesting interventions are viable, supported by the assumption that cost- effective alternatives that can bring in the same amount of water, do not exist; 5) incremental structures lead to incremental benefits; and 6) being small with low water storage and diversion capacities, they do not pose negative consequences for downstream uses.

Lack of Emphasis on Local Water Demand and Potential Supplies

Rainwater harvesting ignores a few critical parameters that govern the potential of rainwater harvesting systems (RWHS) in meeting local water demand, such as: a) the hydrological regime of the region/locality; b) the reliability of the supplies, governed by the reliability of rainfall; c) the constraint imposed by local geological and geo-hydrological settings on recharge potential; and d) the aggregate demand for water from various sectors within the local area.

Some basic hydrological phenomena, which make the abovementioned parameters very critical in deciding the scope of rainwater harvesting and groundwater recharging, are:

- For runoff harvesting, rainfall has to exceed a threshold to generate runoff, though the threshold would vary according to the nature of the soil and land cover of the area. The estimated runoff based on the regression equation arrived at from observed flows in the Hathmati subbasin of the Sabarmati Basin ($R=0.00193*X^{2.022}$) in western India (source: GOG 1994), shows that for the runoff to cross 100 mm, the minimum rainfall required is 682 mm. Whereas in the case of the Kabani subbasin of the Cauvery Basin, runoff starts when the rainfall crosses 366 mm.[1] However, the actual runoff rates would depend on how strong is the correlation between rainfall and runoff in a given basin, and this relation weakens if there is a major year to year change in rainfall intensity and pattern.

- Regions with lower mean annual rainfall experience higher variability and vise versa (Pisharoty 1990). Hence, in regions with lower mean annual rainfalls, rainwater harvesting as a dependable source of water is likely to be low.

- Generally, it has been found that a greater magnitude of annual rainfall means a larger number of rainy days and smaller magnitude of annual rainfall means fewer number of rainy days spread over the rainy season (Pisharoty 1990). The examples of Gujarat further illustrate this (see Kumar 2002b; Kumar 2004). Fewer rainy days also means longer dry spells and thus greater losses from evaporation for the same region.

- High intensity rainfalls are common in the semi-arid and arid regions of India (Garg 1987; Athawale 2003). Higher intensity of rainfall can lead to high intensity in runoff, occurring in short durations, limiting the effective storage capacity of rainwater harvesting systems to almost equal their actual storage size.

- High evaporation during the rainy season means losses from surface storage structures. It also means a faster rate of soil moisture depletion through both evaporation from barren soils and evapotranspiration, which increase the rate and quantum of soil infiltration. This reduces the generation potential of runoff. Among the seven locations in Gujarat for which ET_0 (reference evapotranspiration) data are available, ET_0 during monsoon (June to September) varies from a lowest of 543 mm in Vadodara to 714 mm in Rajkot. The ET_0 as a percentage of annual ET_0, varies from a

---

[1] The regression equation for Kabani estimated by the National Water Development Board, based on observed flows, was R= 0.6363 N-233.7 where N is the rainfall (mm) and R the runoff (mm).

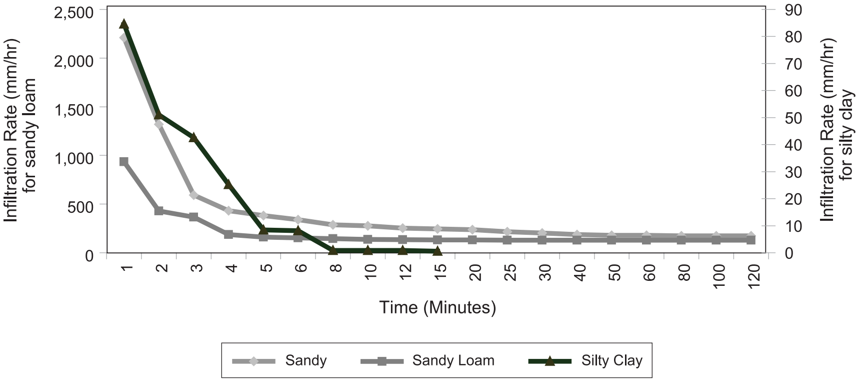
lowest of 33 % in semi-humid Surat to 37.3 % in Bhuj, Kachchh (source: authors' analysis based on data from IMD, Ahmedabad). In the case of Rajasthan, ET_0 during the monsoon ranges from 433 mm in the hill station of Mt. Abu to 967.7 mm in Jaisalmer in the Thar Desert. In percentage terms, it varies from a lowest of 32 % of the total annual ET_0 in Sawaimadhupur to a highest of 49.3 % in Anupgarh (GOR 1992). Among the 10 locations selected along the Narmada Basin in Madhya Pradesh, the values range from 429 mm to 600 mm, with ET_0 as a percentage of total ET_0 ranging from 31.3 % in Betul to 35 % in Mandla (source: GOMP 1972).

- Soil infiltration capacity can be a limiting factor for recharge. In sandy and sandy loam soils, the infiltration capacity of the recharge area can be sustained through the continuous removal of soils. But clayey soils have inherent limitations (see Figure 1). Results obtained from short-term infiltration tests carried out in dug wells in the Andhra Pradesh in two different soil conditions, showed that the infiltration rate becomes negligible (< 0.60 mm/hr) within 10 minutes of starting the test in the case of silty clay, whereas infiltration stabilizes at a rate of 129.1 mm/hour within the first 25 minutes in the case of sandy loam (NGRI 2000). If the infiltration rate approaches to zero fast, it will negatively affect the recharge efficiency of percolation ponds. As thin soil cover has a low infiltration (Muralidharan and Athawale 1998), the extent of the problem would be larger in hard-rock areas (ideal for percolation ponds) with thin soil cover. Dickenson (1994) based on several infiltration studies shows that the rate of infiltration declines to a minimum value within 4-5 days of ponding. This also will have adverse effects on the performance of structures built in areas experiencing flash floods and high evaporation rates, the solutions for which would be wetting or drying of pond-beds through the regulation of inflows.

- For artificial recharge, the storage potential of the aquifer is extremely important. The storage potential of an aquifer vis-à-vis the additional recharge is determined by the characteristics in geological formations, and the likely depth of the dewatered zone.

- In hilly watersheds, the area available for cultivation is generally very low, keeping agricultural water demand low. At the same time, the surface water potential available

Figure 1. Infiltration rate in the sandy loam and silty clay soil at the bottom of a dug well.



> for harvesting is generally high due to high rainfall and runoff coefficients. On the contrary, towards the valleys and plains, the area available for cultivation increases, raising agricultural water demand. At the same time, the surface water potential available for harnessing is generally low due to the lower rainfall, and low runoff coefficients owing to mild slopes, high PET and deeper soil profiles.

The implications of some of these factors on the potential of rainwater harvesting systems are analyzed in the following two sections.

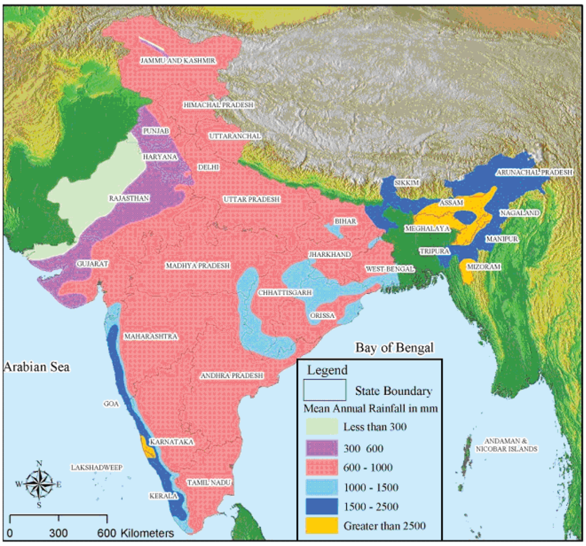
Limitations Imposed by Hydrological Regimes

Local water management interventions are often based on very little understanding of the local hydrological regimes, which govern the potential supplies of water for harvesting. They are rather based on the deep-rooted belief that the greater the size of the water impounding structure, the greater would be the hydrological benefit in terms of water storage and recharge. The best example is the participatory water conservation movement launched by the Government of Gujarat. The government implemented large-scale work for the excavation of thousands of village ponds, irrespective of the nature and size of catchments (Kumar 2002a). Part of the reason is the lack of availability of data on inflows, determined by stream-flows; and outflows, determined by evaporation rates, for small rainwater catchments. While runoff harvesting is most suited to areas with a high ‘runoff catchment area’ to ‘run on’ area ratio (Lalljee and Facknath 1994), this is also ignored. The higher the aridity, the larger would be the required catchment area to the cropped area required for the same water yield (Prinz 2002). Often, encroachment of catchments of water harvesting systems for crop cultivation is very rampant, reducing the runoff prospects.

The states, which have taken up rainwater harvesting and groundwater recharge programs on a large scale, are Gujarat (North Gujarat, Saurashtra and Kachchh), Rajasthan, Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, Madhya Pradesh, Orissa and Chattisgarh. A major part of these regions is covered by six water-scarce river basin systems, namely, Sabarmati, the rivers of Kachchh and Saurashtra, Pennar, Cauvery, east-flowing rivers between Mahanadi and Godavari, east flowing rivers between Pennar and Kanyakumari, which have less than 1,000 m^3 of renewable water per annum (Gupta 2000: pp 116). Now let us look at the hydrological regime existing in these regions.

For this, we first examine the percentage area of each state falling under different rainfall regimes (<300 mm, 300-600 mm, and 600-1,000 mm, 1,000-1,500 mm, 1,500-2,500 mm and >2,500 mm); and different PE regimes (< 1,500 mm, 1,500-2,500 mm, 2,500-3,500 mm and >3,500 mm). It is understood that regions with relatively low rainfall have higher potential evapotranspiration due to relatively low humidity and greater number of sunny days (Pisharoty 1990). Lower rainfall, coupled with higher PE reduces the runoff potential and high evaporation from the impounded runoff, thereby increasing the dryness (Hurd et al. 1999) in the area. The analysis shows that Gujarat and Rajasthan have respectively 11 % and 42 % of area that fall under extremely low rainfalls (< 300mm); and 39 % and 32 %, respectively under low rainfall (300-600 mm). The other states by and large fall under medium rainfall (600 mm-1,000 mm) and high rainfall (1,000-1,500 mm) regimes. In the case of Maharashtra, MP, AP, Karnataka and Tamil Nadu, a lion’s share of the area (85 % and above) falls under the medium rainfall regime. And in case of Orissa and Chattisgarh, 45 % and 40 %, respectively, fall under high rainfall regime (see Map 1).

Map 1. Average mean annual rainfall.



As regards PE, the lion's share of the area in Gujarat and Rajasthan fall under high evaporation (2,500-3,000 mm); nearly 35-56 % of the geographical area of other states (except Orissa and Chattisgarh) falls under high evaporation regimes; the area of these states falling in the medium evaporation regime (1,500-2,500 mm) is in the range of 38-65 %. The entire areas of Orissa and Chattisgarh fall within the medium evaporation regime. Overall, a large section of the area (of the nine states considered) has medium rainfall, and medium to high evaporation. A significant portion of the area (of Gujarat and Rajasthan) has very low to low rainfalls and high evaporation (see Map 2 and Table 1).

Map 2. Average annual evaporation.

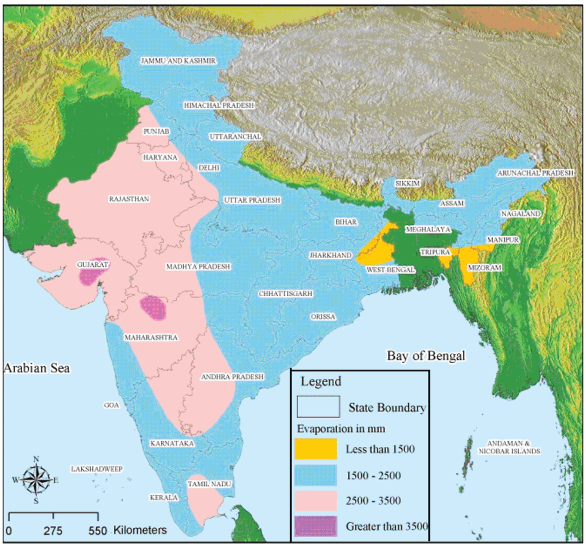


Table 1. Rainfall and PE regimes of states having water harvesting programs.

Name of State	% Area with rainfall in the range of						% of area with evaporation in the range of (PE)			
	<300 mm (very low)	300-600 mm (low)	600-1,000 mm (medium)	1,000-1,500 mm (high)	1,500-2,500 mm (very high)	>2,500 mm (extremely high)	<1,500 mm (low)	1,500-2,500 mm (medium)	2,500-3,500 mm (high)	>3,500 mm (very high)
Gujarat	10.88	39.08	47.27	2.77					88.53	11.47
Rajasthan	41.80	32.45	25.75						100.00	
Maharashtra			85.86	6.93	7.21			37.96	56.23	5.81
Madhya Pradesh			95.71	4.29				56.94	42.89	0.17
Andhra Pradesh			97.83	2.17				52.70	47.30	
Karnataka			88.01	3.65	5.67	2.67		62.82	37.18	
Tamil Nadu			96.52	2.98	0.50			64.56	35.44	
Orissa			54.01	45.99				100.00		
Chattisgarh			59.39	40.61				100.00		

Source: Authors' own estimates based on Pisharoty (1990) using GIS

In the next step, we analyze: the proportion of the geographical area from each of these regions/states falling under different rainfall variability classes like > 25 %, 25-30 %, 30-40 %, 40-50 % and 50 % and above. The higher the magnitude of PET during the monsoon, the higher will be the negative impact on hydrological variables such as surface storage and recharge. While it reduces surface storage through evaporation, the higher PET during the monsoon also means higher crop water requirement during the season and increased soil moisture depletion, leading to reduced recharge from rainfall. In barren soils, higher evaporation rates leads to faster soil moisture depletion perpetuating a higher rate of infiltration of the incoming precipitation and lower runoff.

As Table 2 indicates, a large percentage of the total geographical area of Gujarat and Rajasthan (72 % and 68 %, respectively) has high to very high (30-40 % and above) variability in rainfall. A significant part of the geographical area of the states three to seven in Table 1 (37 % to 92 %) experience medium variability in rainfall; the rest of the area experiences low variability. The entire Orissa and Chattisgarh experience only low variability in rainfall. In a nutshell, more than 50 % of the total geographical area of all the states put together experience medium variability; nearly 25 % experience 'high to very high variability'; and nearly 20 % experience 'low variability' in rainfall (see Map 3). They coincide with 'medium rainfall-medium to high evaporation', low rainfall to very high evaporation' and 'high rainfall to medium evaporation' regimes, respectively.

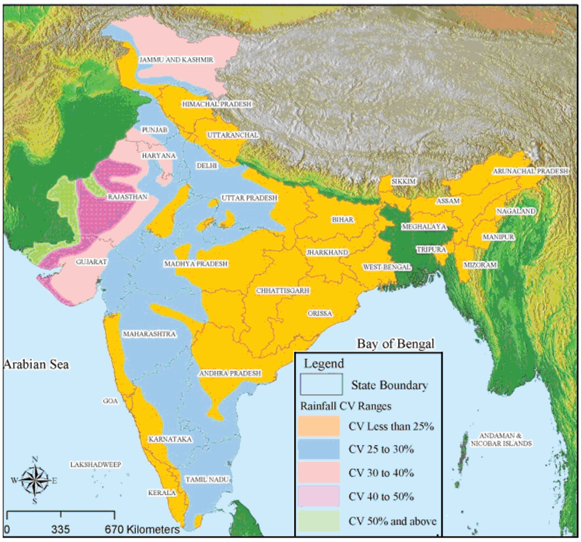
It can be seen from Maps 1, 2 and 3 that regions with high variability in rainfall coincide with those with low magnitudes of rainfall and high PE, which also have a high dryness ratio. In such areas, a slight variation in precipitation or PE can substantially magnify the water-stress on biological systems as compared to humid regions (Hurd et al. 1999). The higher the variability in rainfall, the lower would be the reliability of local water harvesting/recharge systems. This is because the chances of occurrence of low rainfalls and extremely low runoff would be higher

Table 2. Rainfall variability regimes of states having water harvesting programs.

Name of State	% area with rainfall variability in the range of				
	<25 % (low)	25 – 30 % (medium)	30 – 40 % (high)	40 – 50 % (very high)	> 50 %
Gujarat	0.24	27.12	44.30	17.11	11.22
Rajasthan	8.33	24.08	23.04	30.71	13.84
Maharashtra	37.67	62.33			
Madhya Pradesh	49.71	50.29			
Andhra Pradesh	62.64	37.36			
Karnataka	29.15	70.85			
Tamil Nadu	7.73	92.27			
Orissa	100.00	0.00			
Chattisgarh	100.00	0.00			

Source: Authors' own estimates based on Pisharoty (1990) using GIS

Map 3. Average coefficient of variation of rainfall.



under such circumstances, and at the same time, the demand for water would be high due to environmental stress caused by poor soil moisture storage, low runoff and high temperature.

In the third step, we analyze the average number of rainy days and their variability across regions (Table 3). We attempt to find out the percentage of geographical area in each region that falls under different rainy days (say <20 days, 20-30 days, 30-40 days, 40-50 days, 50-75 days, and 75 and above days). We also analyze the implications for the quantum of rainfall in each rainfall event and the maximum and minimum daily rainfalls under different rainfall regimes.

The analysis shows that Gujarat and Rajasthan fall in to the regions that experience fewer days of monsoon rains. To elaborate: nearly 21 % of Gujarat and 45 % of the Rajasthan state

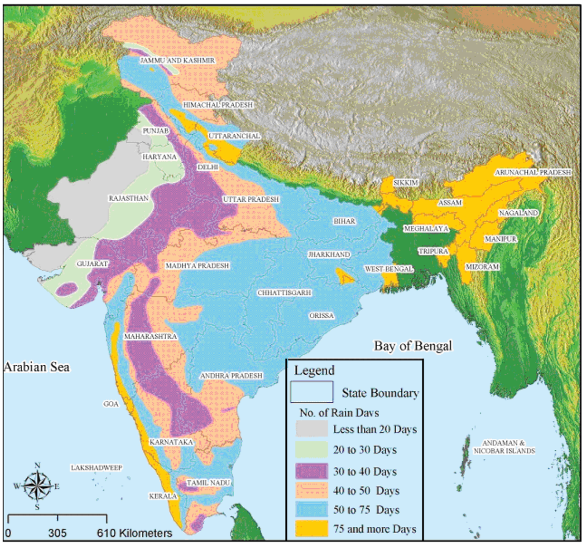
Table 3. Distribution of rainy days in states having water harvesting programs.

Name of State	% of area with rainy days in the range of					
	<20 days	20-30 days	30-40 days	40-50 days	50-75 days	>75 days
Gujarat	20.57	30.87	32.30	6.15	10.11	
Rajasthan	45.31	24.38	28.19	2.12		
Maharashtra			22.57	29.17	43.24	5.01
Madhya Pradesh			21.17	33.26	45.57	
Andhra Pradesh			12.17	29.80	58.03	
Karnataka			26.55	38.79	27.13	7.53
Tamil Nadu			9.35	35.78	54.86	0.01
Orissa					98.77	1.23
Chattisgarh					100.00	

Source: Authors' own estimates based on Pisharoty (1990) using GIS

receive less than 20 days of annual rains; nearly 51 % of Gujarat and 70 % of Rajasthan fall in areas which experience less than 30 days of rain in a year; nearly one-third of both the states receive 30-40 days of rain. As regards the states three to seven in Table 1, the area which receives 30-40 days of rain ranges from 9 to 27 %; 40-50 days of rain ranges from 29-39 %; 50-75 days of rain ranges from 27-58 %. The Western Ghat in Maharashtra and Karnataka receive heavy rains spread over many days (> 75). As regards Orissa and Chattisgarh, both states receive 50-75 days of rain in a year. To sum up, the regions that receive fewer days of rain (erratic rains) coincide with those experiencing low rainfall and high evaporation and high variability in rainfall. The regions that experience many wet days coincide with those which experience high and reliable rainfall and medium evaporation (see Maps 1, 2, 3 and 4).

Map 4. Average rainy days.



By synthesizing the results of the spatial analysis of rainfall, PE, rainfall variability and number of rainy days that are provided in Maps 1-4, the following trends can be established: a) the inter-annual variability in rainfall increases with reducing rainfall; b) the number of wet spells reduces with the lowering magnitude of rainfall; and c) the PE increases with the lowering magnitude of rainfall. The implications of these trends on the potential of water harvesting in a region needs to be understood. The potential for water harvesting is lower when lower rainfall, is coupled with higher potential evaporation and inter-annual variability in rainfall and fewer rainy days. This is due to the following processes. First, the runoff potential by and large would be low in low-rainfall regions with a high dryness ratio. Second, evaporation from surface storage would be high due to high PE. Third, the probability of occurrence of very low rainfalls, causing heavy reductions in runoff, would be high, with consequent hydrological stresses.

Limitations Imposed by the Socioeconomic System

Water harvesting arguments totally miss the water demand-availability perspective at the micro level. Ideally, the RWHS would work if the area which has uncommitted flows to harness has an ‘un-met demand’ or vise versa. This is unlike in large water resource systems where provisions exist for the transfer of water from ‘surplus’ areas to deficit areas.

The water demand of an area is determined by the agro-climate and existing socioeconomic system, which, in fact, gets adjusted by the natural resource environment of the village, the available technologies for accessing them and the institutional and policy environments over a period of time. Regions that were heavily into irrigated agriculture in the past, supported by good water endowments, institutional support and favorable policies, might continue demanding large quantities of water for irrigation even when they run out of water. This is because communities take quite some time to devise coping and adaptive strategies to manage with conditions of water deficits.

Studies in a village in Mandvi taluka of Kachchh, which is one of the most arid districts in India, showed that the annual water withdrawal from aquifers for irrigating crops is 25.42 MCM. The entire water requirement in the village was being met by groundwater, which is experiencing severe over-draft conditions (Kumar 1997). The total amount of rainwater falling in the village is nearly 10.14 MCM (source: based on data provided in Kumar 1997 on geographical area and the mean annual rainfall of Kachchh). With a surface water potential of 0.014 MCM/sq. km (IRMA/UNICEF 2001), the amount of runoff water that would be available for replenishment through natural and artificial recharge from within the village is only 0.40 MCM. The runoff is, therefore, a small fraction of the total consumptive use. This means that the village has to depend on exogenous sources of water for making water use sustainable. What is presented is representative of almost the entire peninsular of India excluding Kerala, central India and western India.

In a village named Manund, in the Patan District of North Gujarat, which has seen widespread pond de-silting, the total groundwater abstraction for agriculture alone was estimated to be 3.78 MCM (or 275 mm), with 35 deep tubewells pumping water at a rate of nearly 15,000 gallons per hour for nearly 1,500 hours a year (Kumar 2000b). The groundwater condition of the village is typical of the North Gujarat region. Against this, the total amount of rainfall over the village is only 7.56 MCM, with a mean annual rainfall of 550 mm over an area of 1,374 ha. The runoff that this amount of rainfall can generate is 63.8 mm as per the rainfall runoff relationship, with the total runoff being 0.877 MCM. But in practice, it is unlikely to get this amount of runoff, as farmers directly harness a significant portion of the runoff generated from the crop land, which falls in the catchment 'in situ' for crop production, unlike large basins which have a good part under virgin catchments. Kumar (2000) estimated the groundwater overdraft in the village as nearly 247.5 mm by considering the recharge as 5 % of the annual rainfall. Hence, even if the entire runoff generated is harnessed for recharge, it would amount to only 25.7 % of the overdraft.

On the other hand, there are many regions in India where the economic demand for water is far below what the natural endowment can provide. The entire Ganga-Brahmaputra Basin area can be put into this category. The region has an enormous amount of static groundwater, estimated to be 8,787.6 BCM, apart from having a high rainfall and cold subhumid climate that generate sufficient surface flows. Cheaper access to water might increase the demand for irrigation water slightly, but, there are significant limits to such access, imposed by the cold and humid climate and very low per capita arable land. The economic demand for water therefore, would continue to be below what the water endowment can provide (Shah 2001; Kumar 2003). Already, the irrigation intensities are high in thee Uttar Pradesh and Haryana. Though irrigation intensity in Bihar is low, the subhumid and cold climate reduces the irrigation requirement significantly. In most parts of this region, the issue is not the physical availability of water, but the ability of communities to access water for irrigation (Kumar 2003; Shah 2001). Water harvesting anyway does not offer any economic solution here for the poorer communities to facilitate their access to water.

Issues in Evaluating Costs and Economics

In the planning of large water resource systems, cost and economics are important considerations in evaluating different options. But unfortunately, the same does not seem to be applicable in the case of small systems, though concerns about economics of recharge systems in certain situations were raised by authors such as Phadtare (1988) and Kumar (2004).

Part of the reason for the lack of emphasis on 'cost' is the lack of scientific understanding of the hydrological aspects of small-scale interventions, such as the amount of stream flows that are available at the point of impoundment, their patterns, the amount that could be impounded or recharged and the influence area of the recharge system. Even though simulation models are available for analyzing catchment hydrology, there are great difficulties in generating vital data at the micro level, especially those on daily rainfall, soil infiltration rates, catchment slopes, land cover and PET, which determine the potential inflows; and evaporation rates that determine the potential outflows. Furthermore, for small water harvesting projects, implemented by local agencies and NGOs with small budgets, the cost of hydrological investigations and planning is hard to justify. Often, provision for such items is not made in small water harvesting projects.

That said, the amount of runoff that a water harvesting structure could capture, depends not only on the total quantum of runoff, but also on how it occurs. A total annual runoff of 20 cm occurring over a catchment of one sq. km. can generate a surface flow of 0.20 MCM, but the amount that could be captured for water harvesting depends on the pattern of rainfall events. As Garg (1987) points out, in arid and semi-arid regions in India, high-intensity rainfalls of short duration are quite common (source: Garg 1987 as cited in Athawale 2003: Figure 24). These runoffs generate flash floods.[2] If the entire runoff occurs in a major rainfall event, the runoff collection efficiency would reduce with the reducing capacity of the structures built. If large structures are built to capture the high-intensity runoff and thereby increase the runoff collection efficiency, the cost per unit volume of water captured would inflate. In fact, authors such as Oweis, Hachum and Kijne (1999) have argued that runoff harvesting should be encouraged in arid areas only if the harvested water is directly diverted to the crops for use.

Given the data on inflows and runoff collection efficiencies, predicting the impacts on the local hydrological regime is also extremely complex, requiring accurate data on geological and geo-hydrological profiles, and variables.

In lieu of the above described difficulties in assessing effective storage of RWHS, unit costs are worked out on the basis of the design storage capacity of the structures and the ‘rule of thumb’ about number of fillings. Shri Vivekananda Research and Training Institute, Mandvi, Kachchh, which had done pioneering work in the field of artificial groundwater recharge in India, often resorts to this rule of thumb to evaluate the cost-effectiveness of the recharge structures they built in Kachchh (see, for instance, Raju (1995)). The recent book by Dr. R. N. Athawale on rainwater harvesting in India though had covered a gamut of technical aspects on water harvesting in the different regions of India, does not deal with economic issues (see, for instance, Athawale 2003).

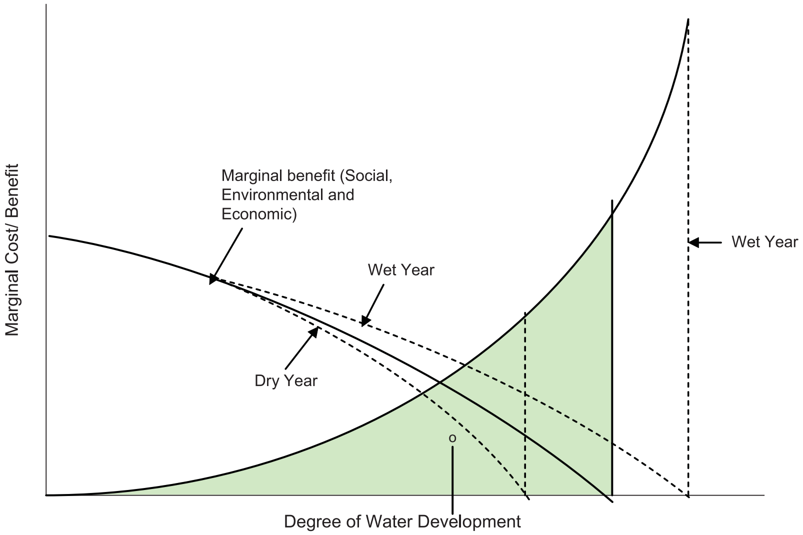
Scale considerations are extremely important in evaluating the cost and economics of water harvesting/groundwater recharge structures because of the hydrological integration of catchments at watershed and river basin levels. The cost and economics of water harvesting systems cannot be performed for individual systems in isolation, when the amount of surplus water available in a basin is limited. This is because incremental structures do not result in a proportional increase in hydrological benefits (Kumar 2000a), as interventions in the upper catchments reduce the potential hydrological benefits from the lower systems. What is important is the incremental hydrological benefits due to the new structure. A system in itself may be cost-effective and economically viable if evaluated independently, but, if evaluated as a part of a large-scale water-harvesting intervention at the level of river basins, the system may not be justifiable from the cost angle when compared against the additional benefit it brings in.

---

[2] Many parts of Kachchh, which records one of the lowest mean annual rainfalls (350 mm), experienced floods during 1992 and 2003 with many water harvesting (WH) structures overflowing. Flash floods occur even in some of the semi-arid and water-scarce basins such as Sabarmati and Banas (Kumar, 2002b).

In any basin, the marginal benefit from a new water harvesting structure would be smaller at higher degrees of basin development, while the marginal cost would be higher (see Figure 2). The reason being: 1) the higher the degree of basin development is, the lower would be the chances for getting socially and economically viable sites for building water impounding structures, increasing the economic and financial cost of harvesting every unit of water; and 2) with a higher degree of development, the social and environmental costs of harvesting every unit of water increases (Frederick 1993), reducing the net economic value of benefits. Therefore, the cost and economic evaluation should move from watershed to basin level. As Figure 2 indicates, the level at which basin development can be carried out depends on whether we consider the flows in a wet year or a dry year or a normal year. Nevertheless, there is a stage of development (marked by O in the chart) beyond which the negative social, economic and environmental benefits start accruing, reducing the overall benefits. Here, O is the optimum level of water resource development.

Figure 2. Marginal cost and benefits of water-harvesting with different degrees of basin development.



But, it is important to keep in mind that the negative social and environmental effects of over-appropriation of the basin's water resources may be borne by a community living in one part of the basin, while the benefits are accrued to a community living in another part. Ideally, water development projects in a basin should meet the needs and interests of different stakeholders living in different parts. Therefore, the optimum level of water development should not aim at maximizing net basin level benefits, but rather optimizing the net hydrological and socioeconomic benefits for different stakeholders and communities across the basin, which amounts to basin-wide optimization. That said, in certain situations, the local economic benefits from RWH against the economic costs themselves may be questionable. But, such interventions could be justified if there are potential social benefits for changing patterns of water availability and use, in terms of increasing water availability to poorer farmers with low-capability landholdings. But such decisions should be based on the evaluation of alternative strategies to meet the local water needs of the poor.

Now, the ability to derive the economic benefits of recharge depends on where the recharged water ends up. In the regions underlain by hard-rock geology, the groundwater flow patterns are quite complex. Often, the benefits are that recharge structures extend up to a few kilometers downstream or upstream depending on the pattern of occurrence of geological structures such as lineaments, fractures and dykes (source: based on Muralidharan and Athawale 1998). Tracing the recharge water in such situations would require sophisticated studies involving isotopes. This is a common problem in the hard-rock areas of Saurashtra, Kachchh, North Karnataka and Tamil Nadu where large-scale water harvesting/groundwater recharge interventions are taken up through check dams, ponds and percolation tanks. Often the communities, for whom investment for recharge systems are made, do not get the benefit (Moench and Kumar 1993). In certain other situations, the recharge water could end up in saline aquifers.

The economics of RWH would also be a function of the incremental value of benefits accrued from the use of newly-added water. Apart from the recharge volume, the value of the use to which the additional water is put is extremely important in determining the incremental benefits, an issue often ignored in the project planning. Often, the benefits of RWHS are not clearly identified or understood. While the cost of water harvesting is significant, it is critical to divert the new water to high-valued uses. Phadtare (1988) pointed out that recharge projects would be economically viable in alluvial North Gujarat if the water is diverted for irrigation, as structures are expensive. Yield losses due to moisture stress are extremely high in arid and semi-arid regions and, that providing a few protective irrigations could enhance yield and water productivity of rain-fed crops remarkably, especially during drought years (Rockström et al. 2003). Therefore, the available extra water harvested from monsoon rains should be diverted to supplementary irrigation in drought years.

There are regions where human and cattle drinking become high priority demands. North western Rajasthan, which is arid and dominated by pastoral communities, named *Gujjars*, is one such example. The social and economic value realized from the use of water for human drinking and livestock use, respectively, would be much more than the economic value realized from the use of water in irrigating crops. In such situations, water should be diverted for such uses where the opportunity costs are low and net value products are high. But proper water use planning to realize the maximum value from the added water is largely missing in water harvesting efforts.

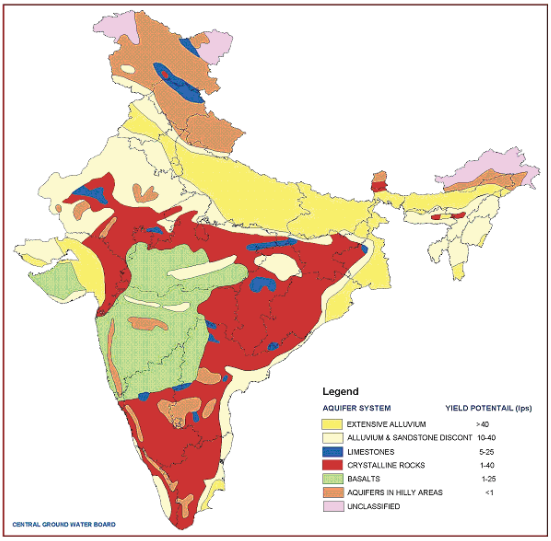
Lack of an Integrated Approach

In many river basins, the surface water systems and groundwater systems are often interconnected. Any alterations made in one type of system could change the availability of water in the other type (Sohiquilo 1985; Llamas 2000). In many hilly areas, especially in the Western Ghats, the water levels rise steeply after the monsoon, and groundwater contributes significantly to the stream flows downstream during lean seasons due to the steep gradients for groundwater flow. In such cases, any water harvesting intervention to store water underground may not make much sense as the water stored would be rejected and appear as surface flows (Mayya 2005). On the other hand, in regions with deep water table conditions like in North Gujarat, the runoff directly moves into the groundwater systems of the plains through the sandy river bed as dewatering of the upper aquifers increases the rate and quantity of percolation (Kumar 2002b).

With two-third of the country's geographical area underlain by hard-rock formations, the storage capacity of aquifers poses a major challenge for artificial recharge. Most parts of water-scarce states, viz., Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, Orissa, Chhattisgarh and Tamil Nadu are underlain by hard rocks ranging from basalt, crystalline granite, hill aquifers and sandstone. A small area in Gujarat has extensive alluvium e.g., Narmada Valley and Cambay Basin (see Map 5). The hard rock aquifers have no primary porosity and have only secondary porosity. The constraints imposed by hard-rock geology in recharge efforts through percolation tanks are: high depth to the water table below and around the recharge structure due to the occurrence of recharge mounts and shallow bed rocks, which prevent the percolation of water (Muralidharan 1990 as cited in Muralidharan and Athawale 1998); and low infiltration capacity of the thin soils overlaying the hard-rock formations. Due to low specific yield (0.01-0.03), the sharp rise in water levels is observed in aquifers during monsoon, leaving little space for infiltration from structures. While harnessing water for recharge is extremely important during normal and wet years, the natural recharge in hard-rock formation is high during such years as it is a function of seasonal rainfall (based on regression equations shown in Figure 7 in Athawale 2003), further reducing the scope for artificial recharge.

In Saurashtra, in spite of the poor potential offered by low rainfalls, high variability, and high evaporation rates (see Map 1-3), significant recharge efforts were made. But, the biggest constraint in storing water underground during high rainfall years is the poor storage capacity or specific yield of the basalt formations. During good rainfall years, the aquifers get saturated

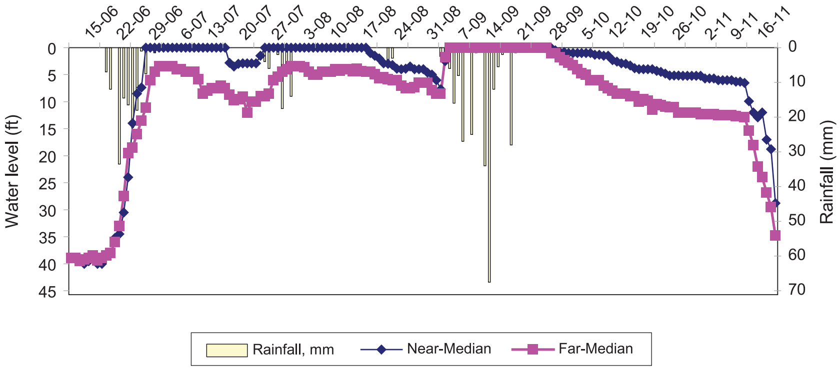
Map 5. Aquifer system in India.



with natural recharge immediately after the rains, leaving no space for entry of water from the recharge systems (Kumar 2000a). An estimated 20,000 check dams built in the region to capture the rainwater and recharge the aquifers are able to store only a small fraction of the surplus runoff. In such situations, proper water use programing is required to achieve effective utilization of the available surplus water, wherein water from aquifers is pumped out and used during the rainy season itself thereby creating storage space for the incoming flows (Muralidharan and Athawale 1990; Shah 2002).

The groundwater level fluctuation data obtained from the Ghelo River basin in Saurashtra illustrate this. The basin had experienced intensive water-harvesting since 1995. The data were collected from open wells located inside the basin periodically during and after the monsoon rains. The wells located close to the water harvesting structures and those away from the structures are demarcated. The water level fluctuation in the wells, in relation to the rainfall events, was analyzed and presented in Figure 3. The time series data shows that the wells close to water harvesting structures are replenished faster than those located away from the structures. But, these wells that are replenished faster start overflowing after the first major wet spell, while the second category of wells show similar trends only after the second wet spell. Another interesting observation is the steep rise in water levels in wells located both close to and away from the water harvesting structures soon after the first wet spell. This steep rise in water levels (in the order of 35-40 feet) is indicative of the poor specific yield of the aquifer in the area,[3] as the magnitude of cumulative rainfall that had caused this fluctuation is quite small (nearly 200 mm).

Figure 3. Water level fluctuation in wells in Fulzar, Ghelo River basin.



---

[3] The specific yield can be estimated as the ratio of the rise in water level (m) and the cumulative rainfall (m) that is responsible for the water level fluctuation, if we consider the lateral flows in groundwater as negligible and assume that pumping from the observation wells during the time of recharge is zero. The rise in water level is between 10.5 and 12 m and the rainfall is 0.2 m.

Trade-off between Local vs Basin Impacts in Closed Basins

Due to the lack of integration between plans for water harvesting at the local level and basin level water resource development, RWH often leads to over-appropriation of surface water in river basins. While the planning of conventional water development projects is based on dependable yields from the catchments, the subsequent plans for WH do not take into account the ‘committed flows’ for downstream reservoir/water diversion systems. Also, there is an increasing tendency to believe that because these structures are too small that they are benign (Batchelor et al. 2002), though present in large numbers in most cases. The primary reason for this is that the agencies that are concerned with small water harvesting (in the upper catchment) are different to those that are concerned with major head- works, and the two types of agencies do not act in a coordinated fashion at the basin level. The building of small water harvesting systems such as tanks and check dams are often the responsibility of the minor irrigation circles of the irrigation department or district arms of the rural development departments of the states concerned. This ad hoc approach to planning often leads to over-appropriation of the basin water, with negative consequences for large schemes downstream (Kumar et al. 2000).

The data collected from the Ghelo River basin shows that the inflow into Ghelo-Somnath Reservoir had significantly reduced after intensive water harvesting work was undertaken in the upper catchment. Figure 4 shows the catchment rainfall and runoff in the Ghelo-Somnath. Since 1995, the year that experienced intensive water harvesting work, the only time the reservoir overflowed was in 2005, when the recorded rainfall was 789mm. While reduction in runoff could be attributed to rainfall reduction as well, rainfall-runoff regressions were carried out for two time periods i.e., 1969-1995 and 1995-2005. The regression equations clearly show that the relationship between rainfall and runoff had changed after water harvesting interventions (see Figure 5). For the same amount of rainfall, the runoff generated is now low. Or in other words,

Figure 4. Ghelo-Somnath rainfall and reservoir inflows.

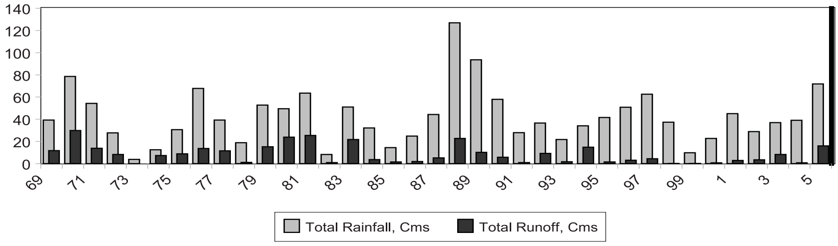
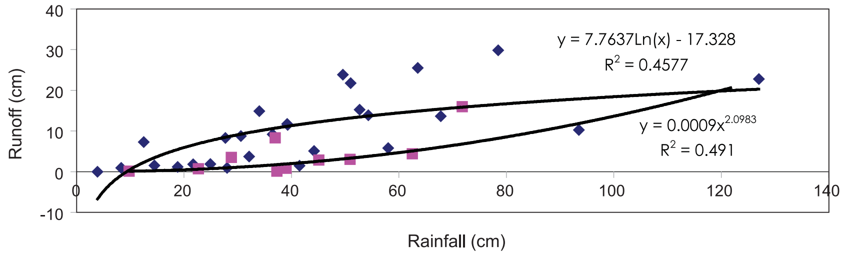


Figure 5. Impact of water harvesting on inflows in the Ghelo-Somnath Reservoir.



the amount of rainfall required for filling the reservoir had now increased from 320 mm to 800 mm. While this is theoretically true, the actual runoff received by the station might actually differ as there are many factors other than just rainfall magnitude, which determine the runoff rates. Though the curves intersect, at high magnitudes of rainfall, this is not a problem as such high rainfall does not occur in the basin, and the curve needs to be considered only for the rainfall regime of the basin.

Many large and important river basins in India, which are also facing water scarcity, are now 'closed' or do not have uncommitted flows that are utilizable through conventional engineering interventions. For example, the river basins of Pennar, Cauvery and Vaigai in the south (based on GOI 1999: pp 472-477), and Sabarmati and Banas in the west, and all the west-flowing rivers in Saurashtra and Kachchh in Gujarat, are closed (Kumar 2002). While the Krishna Basin too is on the verge of closure, basins such as the Godavari and Mahanadi in the east are still 'open' (based on GOI 1999: pp 466-469).

The Sabarmati Basin, for instance, having a drainage area of 21,678 sq. km., has a utilizable surface flow of 1,513.4 MCM allocated to Gujarat (Kumar and Singh 2001), whereas the total live storage capacity of irrigation schemes built in the basin, estimated to be at 1,470 MCM (GOI 1999), is still slightly below this. But the basin has many water diversion structures including weirs and a barrage. Actually, the dependable runoff upstream of the reservoirs/ diversion structures in the basin is far below the planned water utilization (estimated to be at 1,560 MCM as per Kumar and Singh (2001), leaving no spillover. At the aggregate level, the basin is over-appropriated. At the subbasin level, the scenario is different. Two of the subbasins, viz., Dharoi and Hathmati are heavily over-appropriated (Kumar et al. 2000). Still, one of the subbasins, named Watrak, has uncommitted flows (Kumar and Singh 2001), which eventually end up in the Gulf of Cambay.

It is hard to judge whether a basin is closed or open on the basis of the storage capacity of reservoirs and the dependable flows as many reservoirs also divert a lot of water during the monsoon season, increasing the effective water utilization to be greater than the live storage capacity. Figure 5 shows the ratio of total live storage of reservoirs (built, being built and proposed) in 17 major river basins in India against the dependable runoff in these basins. It shows that for many basins, the ratio is far less than 100 %, leaving the impression that there are much more uncommitted flows in the basin for future harnessing. But this is not correct. Take, for instance, the Narmada Basin. The total live storage volume of all terminal dams built in Narmada, i.e., Sardar Sarovar, is 5,800 MCM, where as the total water utilization from this reservoir is 11, 200 MCM. All the 30 large and 135 medium reservoirs together would divert a total of 30,588 MCM of water for irrigation and various other purposes (NWDA 2004). But the total live storage of these reservoirs would be much less, i.e., 23,790 MCM (GOI, 1999: pp 36). This is because a significant amount of water would be diverted from these reservoirs for kharif irrigation within the basin and outside, particularly from the Sardar Sarovar Reservoir. Again the estimates of the stages of development do not take into account the reservoirs having a live storage capacity of less than 10 MCM.

Trade-off between Economics and Hydrological Opportunity

Regions with semi-arid and arid climate experience extreme hydrological events (Hurd et al. 1999). As we have seen before high inter-annual variability in rainfall is a common phenomenon in most parts of these water-scarce regions. Rainfall variability induces a higher degree of variability in runoff. Such a high variability is found even in high rainfall regions as well as low rainfall regions. We take the example of the upper catchment area of the Cauvery Basin in peninsular India and one of the catchments of Sabarmati River basin in North Gujarat of western India.

In the Palanpur area of Banaskantha District in North Gujarat, which has semi-arid to arid climatic conditions, the rainfall records show a variation from a lowest of 56 mm in 1987 to a highest of 1,584 mm in 1907. The runoff estimated on the basis of regression equation developed for a subbasin, named Hathmati of the Sabarmati Basin in North Gujarat, which is physiographically quite similar to the Palanpur area of Banaskantha, shows that the runoff can vary from a lowest of 0.6 mm to a highest of 541 mm. But the occurrence of actual runoff could be different from this based on how other variables that are not considered in the regression viz., the intensity and pattern (over space and time) of rainfall, influence the runoff intensity. Thus the lowest runoff is close to one-thousandth of the highest runoff. Though what can occur at the subbasin level may not be representative of that in small upper catchments, the difference cannot be drastic. Even for the humid, high rainfall region of the Wayanad District in Kerala, the observed rainfall of the area range from 528 mm in the lowest rainfall year (2002) to 1,458 mm in the highest rainfall year (1994) in a 31-year period from 1973-2003.

When there is a high inter-annual variability in the runoff a catchment generates, a major planning question which arises is ‘for what capacity the water harvesting system should be designed’? When scarcity is acute, the highest consideration is given to capturing all the water that is available. If all the runoff that occurs in a high rainfall year is to be captured, then the cost of building the storage system would be many hundred times more than what is required to capture the runoff which occurs during the lowest rainfall, and, the system would receive water to fill only a small fraction of its storage capacity in the rest of the years. This could make it cost-ineffective. The issue of variability is applicable to the design of large head-works as well. But, in large systems, the water in excess of the storage capacity could be diverted for irrigation and other uses to areas that face water shortages during the same season, thereby increasing the effective storage.

In order to illustrate this point, we used the data generated from the Ghelo River basin in Saurashtra. The basin has a total catchment area of 59. 20 sq. km. It has a medium irrigation reservoir with a storage capacity of 5.68 MCM and that has been functional since 1966. The inflow data of the reservoir for the period 1969-1995 showed that the total runoff generated in the basin varied from zero, in the year which recorded a rainfall of 39 mm, to a maximum of 17.78 MCM in the year which recorded a rainfall of 1,270 mm. Today, the total capacity of water harvesting systems built in the upstream of the Ghelo Reservoir is 0.15 MCM. During the period from 1969 to 2005, the reservoir showed an overflow for 13 years with a total quantum of 60.936 MCM. Capturing one million cubic meters of runoff had to be captured in addition to the 5.89 MCM that would be captured by the medium irrigation reservoir, would cost around 0.09 X/m^3 of water, while capturing 3 MCM would cost 0.11 X/m^3 of water. If the maximum runoff observed in the basin, i.e., 17.785 MCM has to be captured, the total volume of water captured would be only 60.91 MCM, in which case the unit cost of water harvesting would be around 0.21 X/m^3 of water. Here, ‘X’ is the cost of storage structures for creating an effective storage space of one MCM. Here, again, we are not considering the incremental financial cost of the special structures for capturing high magnitudes of runoff, which cause flash floods.

Maximizing Local Benefits vs Optimum Benefits for Basin Communities

Generally, in any river basin, the upper catchments are rich in terms of their ability to contribute to the basin yields. This is mainly because of the unique physiographical features, and partly because of climatic conditions such as steep slopes, high rainfall in the mountains and high humidity, which provide a favorable environment for runoff generation. The upper catchments also provide a good source of base flows due to the forest cover, which causes favorable conditions for water storage and infiltration. On the demand side, these regions generally are less endowed in terms of the availability of arable land. Over and above, the demand rates for irrigation are generally low. On the other hand, the lower catchments are generally characterized by lower rainfalls and higher levels of aridity (rainfall deficit to meet ET demands) and better access to arable land, thereby increasing the aggregate demand for irrigation.

There are numerous examples for this and a few to cite are: the upper catchment of the Cauvery Basin in the south, the Narmada Basin in central India, the Sabarmati Basin in western India, the tributaries of the Indus River in north western India, the Krishna Basin in central India and the Mahanadi Basin in eastern India. Certain parts of the Kabani Subbasin of the Cauvery River basin have a cold and semi-humid climate, while certain other parts of this subbasin receive the second highest rainfall in India after Chirapunji, with the mean annual rainfall exceeding 4,000 mm. Irrigation demands in these regions are low owing to high precipitation and low reference evapotranspiration, and the low per capita availability of arable land**.** On the other hand, the lower parts of the Cauvery Basin in Tamil Nadu are hit by a scarcity of water for irrigation owing to lower rainfalls and high evapotranspiration.

We have defined agricultural water demand as a function of per capita net sown area and the ratio of ET_0 (reference evapotranspiration) and rainfall; and water availability as a function of rainfall. It is assumed that: a) higher the ET_0/R ratio, higher would be the irrigation requirement for a unit of land; and b) higher the per capita (rural population) net sown area, higher would be the aggregate demand for irrigation per capita. Table 4 shows the estimated values of two selected agricultural water demand variables, viz., ET_0/R and per capita arable land; and one water availability variable, i.e., rainfall. It also shows that the irrigation demand is much higher in the lower catchment areas, while water availability is higher in the upper catchments in all six of these important basins.

Major water resource/irrigation projects undertaken in the past, tap stream flows generated from the upper catchments but cater to either the lower parts of these basins or other less water endowed regions outside these basins (Verghese 2001 and 2002). The Bakhra Reservoir and Nangal diversion projects located in the high rainfall Shivalik Hills of Himachal Pradesh, essentially cater to the ravenous low rainfall and drought-prone regions of Punjab and scanty rainfall regions of Rajasthan (Verghese 2002). The Sardar Sarovar Dam harnesses water from ample rainfall areas in the Narmada Valley and takes it to the drought-prone areas of North Gujarat and Saurashtra, which are characterized by low and erratic rainfall (Verghese 2001). Similarly, the large reservoir projects in the Cauvery Basin transfer water to the drought-prone regions in Tamil Nadu and Karnataka. As such the water demand for irrigation is extremely low in the upper catchments.

Moreover, as irrigation water use efficiency and water productivity are likely to be high in areas with variability in rainfall and high drought- proneness (Rockström 2002), with transfer of water from the well-endowed regions to the poorly-endowed regions, the economic value of water in agriculture increases. The recent research carried out by IWMI in water-scarce and

Table 4. Comparison of agricultural water demand variables in upper and lower catchment districts of selected Indian river basins.

Name of Basin	Name of Upper Catchment District (UCD)	Name of Lower Catchment District (LCD)	Mean Annual Rainfall (mm) in		Mean Annual Potential Evapo-transpiration (mm) in		PET/R		Per Capita Net Sown Area(ha)	
			UCD	LCD	UCD	LCD	UCD	LCD	UCD	LCD
Sabarmati	Dungarpur	Ahmedabad	643.7	821.0	1,263.0	1,788.8	1.96	2.18	0.14	0.47
Indus	Shimla	Ludhiana	1,597.0	525.0	986.60	1,698.6	0.62	3.24	0.14	0.25
Narmada	Shahdol	Jhabua	1,352.0	792.04	1,639.0	2,127.0	1.21	2.69	0.35	0.35
Cauvery	Wayanad	Nagapattianan	3,283.0	1,337.0	1,586.9	1,852.5	0.48	1.39	0.18	0.13
Krishna	Raigarh	Guntur		1,029.0		1,785.9		1.74	0.13	0.22
Mahanadi	Raipur	Puri	1,388.0	1,440.0	1,667.0	1,667.0	1.20	1.16	0.18	0.06

Source: authors' own estimates based on Agricultural Statistics of India and FAO data on precipitation (R) and reference potential evapotranspiration (PET)

Notes: UCD: Upper catchment district; LCD: Lower catchment district

land-rich western Punjab and water-rich and land-scarce eastern Uttar Pradesh (UP) showed that the value of water realized from irrigation is much higher in Punjab than in eastern UP. The economic value of water was Rs. 14.85/m^3 in western Punjab, whereas in eastern Uttar Pradesh it was Rs. 11/m^3. Due to the scarcity of water, the farmers in Punjab make better economic use of water by choosing cropping systems that are economically more efficient and adopting agronomic practices in order to obtain higher yields, higher physical productivity and economic efficiency (Kumar, Malla and Tripathy 2006).

But, often water harvesting initiatives, especially those by NGOs, are driven by considerations other than economic efficiency, the most important of which are social equity and environmental justice. Impounding water in the upper catchments might serve the social objectives of meeting drinking water requirements.

As evident from the above illustrations, there is a clear trade off between meeting economic efficiency objectives and these developmental goals. Therefore, any water resource intervention in the upper catchment areas that reduces the downstream uses should be done with due consideration to the net change in the 'gross value product' of water in the basin due to the interventions. The 'gross value product' can be defined as the sum total of the incremental value product from the economic uses, environmental services and social uses that the basin's water resources meet. The amount of water to be captured upstream through RWH interventions should also be optimized to derive maximum regional social equity, environmental value and overall output from the economic uses of water. In basins where the available water resources are already committed (closed basins), the challenge is bigger as maximizing the gross value product might mean reallocating some water from a low valued use to a high valued use.

Major Findings

The following are the major findings that emerge from an extensive review of the research on water harvesting in India, and a macro analysis of the critical issues in rainwater harvesting from the point of view of hydrological opportunities, economic viability and socioeconomic impacts when scale considerations are involved.

- Macro level hydrological analysis shows that rainwater harvesting solutions offer extremely limited potential in terms of their ability to reduce the demand-supply imbalances and provide reliable supplies to water-scarce regions. The reason being: a) a significant part of these regions (states of Gujarat and Rajasthan) are characterized by low mean annual rainfalls, high inter-annual variability in rainfall, with high potential evaporation and a larger share of evaporation occurring during the rainy season, reducing runoff potential and increasing the occurrence of hydrological stresses; and b) another significant part is characterized by medium rainfalls, with medium inter-annual variability, but 'medium to high evaporation', making surface storage difficult.

- A large part of the water-scarce regions, which fall under the 'medium rainfall-medium to high evaporation' regime are underlain by hard-rock formations such as basalt, crystalline rocks and other consolidated formations, e.g., sandstones. The percolation tanks, which are the most preferred recharge structures, are likely to have low efficiency in these hard-rock areas and also in areas having silty clay and clayey soils. In high rainfall, and medium evaporation regions, which experience high reliability in rainfall, such as parts of Orissa and western Ghat, the overall potential and reliability of water supplies from RWHS would be high.

- Inefficient recharging in hard-rocks is due to a lack of integration of groundwater and surface water use. In these regions, the planning of recharge schemes should consider the surface water impoundment of all the available excess flows, than their direct recharge. This should be followed by water use programming to create an underground storage for incoming surface flows. However, this is not followed. The data on water level fluctuations collected from the Ghelo River basin in Saurashtra show that wells in the vicinity of check dams start overflowing during the monsoon due to lack of storage capacity in the shallow aquifer, which gets recharged.

- Many water-scarce regions have water demands that far exceed the supply, and being vulnerable to hydrological stresses, they would require exogenous water.

Economic evaluation of water harvesting/groundwater recharge systems poses several complexities due to the difficulty in quantifying the inflows, the storage and recharge efficiency, and the economic value of the incremental benefits, which are social, direct economic and ecological or environmental. Data for water harvesting structures constructed in the upper catchment shows a storage capacity of 0.15 MCM. At the same time, the estimated inflow reduction in the reservoir downstream (Ghelo-Somnath) was not found to be constant, but a function of the rainfall itself. The flow reduction is highest at below normal to normal rainfall regimes, whereas at higher levels of rainfall it appears to reduce.

- Scale considerations are extremely important in evaluating the cost and economics of water harvesting/groundwater recharge structures because of the integration of catchments at the level of river basins. The economics of water harvesting cannot be performed for structures based on their individual benefits and costs when the amount of surplus water available in a basin is limited; but on the basis of incremental benefits. Furthermore, the higher the degree of basin development, the higher will be the marginal cost and the lower will be the marginal benefit.

- There are many basins which cover significant areas in India that experience high inter-annual variability in the stream flows are many. In such basins, the trade-off between the hydrological impacts of water harvesting and the economic benefits is likely to be large. With the increasing storage capacity of RWH systems, the economic viability becomes poorer as the average cost of water harvesting per unit volume of water increases. The historical data on reservoir inflow obtained for the Ghelo River catchment illustrate this.
- In ‘closed basins’, there is an apparent trade-off between local benefits and downstream benefits. Upstream diversions reduce the prospects of storage and diversions systems in the downstream. Examples of closed basins are river basins in North Gujarat, Saurashtra, Kachchh, western Rajasthan and basins in peninsular India, such as Cauvery, Pennar and Vaigai. Narmada is another basin, which in the immediate future would join this category of river basins. The detailed hydrological data collected from the Ghelo River basin in Saurashtra also illustrate this.
- In many important basins, there is an apparent trade-off between maximizing the overall benefits for basin communities in terms of enhancing the gross value of product of water, and maximizing the local benefits of water harvesting. This is owing to the fact, that in these basins, water from well-endowed regions with low water demands is being diverted to poorly-endowed regions with high water demands, enhancing its social and economic value. Noteworthy examples are Indus in north-western India, Cauvery and Krishna in the southern peninsula, Narmada in central India and the Sabarmati Basin in western India.

Conclusions

In the most water-scarce regions of India, RWH offers limited potential. In many other regions, which have medium rainfalls but experience ‘medium to high evaporation’, the poor groundwater potential of the hard-rock that underlie these regions pose a constraint for recharging. This was illustrated by water-level fluctuation data in the wells of the Ghelo River basin in Saurashtra. The economic evaluation of water harvesting systems poses several complexities due to the problems in quantifying their hydrological impacts, and their various benefits. The economics of water harvesting cannot be worked out for structures on the basis of individual benefits, but on the basis of incremental benefits. In many water-scarce basins, there is a strong trade-off between maximizing the hydrological benefits from RWH and making them cost-effective. In many water-scarce basins, RWH interventions lead to the distribution of hydrological benefits rather than to their augmentation. This was also illustrated by the historical flow series data from the Ghelo River basin. There is an optimum level of water harvesting that a basin can undergo to optimize the gross value product of water vis-à-vis economic, social and environmental outputs basin-wide.

References

Agarwal, A.; Narain, S. 1997. *Dying Wisdom: Rise and Fall of Traditional Water Harvesting Systems*, Centre for Science and Environment. New Delhi, India: Centre for Science and Environment.

Athawale, R. N. 2003. *Water Harvesting and Sustainable Supply in India*, published for Environment and Development Series, Centre for Environment Education, Rawat Publications, Jaipur and New Delhi.

Batchelor, C.; Singh, A.; Rama, M.S.; Rao, M.; Butterworth, J. 2002. Mitigating the Potential Unintended Impacts of Water Harvesting, paper presented at the IWRA International Regional Symposium 'Water for Human Survival', 26-29 November, 2002, Hotel Taj Palace, New Delhi.

Badiger, S.; Sakthivadivel, R.; Aloysius, N.; Sally, H. 2002. Preliminary Assessment of a Traditional Approach to Rainwater Harvesting and Artificial Recharging of Groundwater in Alwar District, Rajasthan, paper presented at the annual partners' meet of IWMI-Tata Water Policy Research Program, Anand, February 19-20.

Boughton, J. C.; Stone, J.J. 1985. Variation of Runoff with Watershed Area in a semi arid Location. *Journal of Arid Environment* Vol. 9, pp13-25.

Down to Earth. 2004. Water Woes in Wet Kerala, Cover Story, *Down to Earth*, May 31, pp 26-33.

Evans, J. P.; Jakeman, A.J. (undated) Development of a Simple, Catchment-Scale, Rainfall-Evaporation-Runoff Model, Centre for Resource and Environmental Studies, The Australian National University, Canberra ACT 0200: http://earth.geology.yale.edu/~je84/mystuff/research/ems_paper.pdf.

Frederick, K. D. 1993. *Balancing Water Demand with Supplies: The Role of Management in a World of Increasing Scarcity*, Technical Paper 189, Washington D. C: World Bank.

Garg, S. K. 1987. *Hydrology and Water Resources Engineering*, Khanna publishers, Delhi, pp.110-181.

Government of Gujarat. 1994. Integrated Plan of Sabarmati River Basin, Draft Report prepared by Gujarat State Water Resources Planning Group, Gandhinagar, Gujarat.

Government of India. 1999. Integrated Water Resource Development: A Plan for Development, Report of the National Commission for Integrated Water Resources Development Vol. I, Ministry of Water Resources, Government of India, New Delhi.

Government of Madhya Pradesh. 1972. *Master Plan for Development of Water Resources of The Narmada in Madhya Pradesh*, Volume –II, Statements, Government of Madhya Pradesh.

Government of Rajasthan. 1992. Effect of Rainfall and Potential Evapo transpiration on Groundwater Levels of Rajasthan, Groundwater Department, Jodhpur.

Gupta, R. K. 2000. Regional Water Transfer and Human Rights: Some Reflections on Sardar Sarovar Project, *ASIAN Journal* (Formerly Journal of Transportation and Infrastructure, 7 (4) pp: 112-127.

Hira, G. S.; Khera, K.L. 2000. Water Resource Management in Punjab under Rice Wheat Production System, Department of Soils, Punjab Agricultural University, Ludhiana.

Hurd, B.; Leary, N.; Jones, R.; Smith, J. 1999. Relative Regional Vulnerability of Water Resources to Climate Change, *Journal of the American Water Resources Association*, 35 (6): 1399-1419.

Jakeman, A.; David, J.; Post, A.; Beck, M.B. 1994. From data and theory to environmental models, *Environmetrics*, 5, 297-314.

Kolarkar, A. S.; Murthy, K.; Singh, N. 1983. Khadin-a method of harvesting water for agriculture in the Thar desert, *Arid Environment*. 6: 59-66.

Kumar, M. D. 1997. Water Use Study for Coastal Saurashtra and Kachchh, report submitted to the Water Resources Development and Management (WARDEMA) Project, Rajkot, VIKSAT, Ahmedabad.

(2000a) Dug-well Recharging in Saurashtra: Are the Impacts and Benefits Over-stretched? *Journal of Indian Water Resources Society*, July.

(2000b) Institutions for Efficient and Equitable Use of Groundwater: Irrigation Management Institutions and Water Markets in Gujarat, Western India. *Asia-Pacific Journal of Rural Development*, Vol. X (1), July.

(2002a) Integrated Water Management in the face of Growing Demand and threatened Resource Base in North Gujarat: Constraints and Opportunities: A Pilot Project to protect North Gujarat's Groundwater Ecology and Agriculture Economy, paper presented at the annual partners' meet of the IWMI-Tata Water Policy Research Programme, Anand, February 19-20.

(2002b) *Reconciling Water Use and Environment: Water Resource Management in Gujarat, Resource, Problems, Issues, Strategies and Framework for Action*, report submitted to Gujarat Ecology Commission for the Hydrological Regime Subcomponent of the State Environmental Action Programme supported by the World Bank.

Kumar, M. D. 2003. Food Security and Sustainable Agriculture in India: The Water Management Challenge, Working Paper 60, International Water Management Institute, Colombo, Sri Lanka.

Kumar, M. D. 2004. Roof Water Harvesting for Domestic Water Security: Who Gains and Who Loses? *Water International*, 39 (1): 43-53.

Kumar, M. D.; Chopde, S.; Mudrakartha, S.; Prakash, A. 1999. "Addressing Water Scarcity: Local Strategies for Water Supply and Conservation Management in Sabarmati Basin, Gujarat," in M. Moench, E. Caspari and A. Dixit (eds.) *Rethinking the Mosaic: Investigations into Local Water Management*. Kathmandu and Boulder: Nepal Water Conservation Foundation and Institute for Social and Environmental Transition.

Kumar, M. D.; Ballabh, V.; Talati, J. 2000. Augmenting or Dividing: Surface water Management in the Water Scarce River Basin of Sabarmati, IRMA Working Paper 147, Institute of Rural Management, Anand.

Kumar, M. D.; Malla, V.J.; Tripathy, S. 2006. Value of Water in Agriculture: A Comparative Analysis of Water Scarce and a Water Rich Region, *Water International*, paper accepted.

Lalljee, B.; Facknath, S. 1999. Water Harvesting and Alternative Sources of Water for Agriculture, PROSI Magazine, September 1999.-N 368-Agriculture.

Llamas, M. R. 2000. La Inserción De Las Aguas Subterráneas En Los Sistemas De Gestión Integrada, Paper presented at *II Congresso Ibérico Sobre Planeamento E Gestão De Água*, 9-12 November 2000, Oporto.

Moench, M.; Dinesh Kumar, M. 1993. Local Water Management Initiatives: NGO Activities in Gujarat, VIKSAT-Pacific Institute Monograph, VIKSAT, Ahmedabad.

Molle, F.; Mamanpoush, A.; Miranzadeh, M. 2004. *Robbing Yadullah's Water to Irrigate Saeid's Garden Hydrology and Water Rights in a Village of Central Iran*, Research Report 80, International Water Management Institute, Colombo, Sri Lanka.

Muralidharan, D.; Athawale, R.N. 1998. Artificial Recharge in India, base paper prepared for Rajiv Gandhi National Drinking Water Mission, Ministry of Rural Areas and Development, National Geophysical Research Institute.

National Geo-physical Research Institute. 2000. Geo-hydrological Investigations in M. C. Tanda Watershed, Anantapur District for Formulation of Suitable Artificial Recharge Strategies, interim report, September.

Oweis, T.; Hachum, A.; Kijne, J. 1999. Water Harvesting and Supplementary Irrigation for Improved Water Use Efficiency in Dry Areas. SWIM Paper, Colombo, Sri Lanka.

Pandey, D. N.; Gupta, A.K.; Anderson, D.M. 2003. Rainwater harvesting as an adaptation to climate change, Review Article, *Current Science*, 85 (1), 10 July.

Patel, A. S. 2002. Impact of Groundwater Recharge Activities in Saurashtra, paper presented at the annual partners' meet of the IWMI-Tata Water Policy Research Programme, Anand, February 19-20.

Phadtare, P.N. 1988. Artificial recharge of groundwater, paper submitted in the meeting of the working group on Water Harvesting, NCL, Pune, August 5, 1988.

Phansalkar, S.; Verma, S. 2004. “Improved Water Control as a Strategy for Improving Tribal Livelihoods,” Review of Agriculture, *Economic and Political Weekly*, XXXIX (12).

Pisharoty, P. R. 1990. Characteristics of Indian Rainfall, Monograph, Physical Research Laboratories, Ahmedabad.

Prinz, D. 2002. The Role of Water Harvesting in Alleviating Water Scarcity in Arid Areas, Keynote Lecture, Proceedings, International Conference on Water Resources Management in Arid Regions. 23-27 March, 2002, Kuwait Institute for Scientific Research, Kuwait (Vol. III. 107-122).

Raju, K. C. B. 1995. Rainwater Harvesting for Groundwater Recharging: The Experience of SVRTI in Moti Rayan Village, Kachchh in Moench, M. (Ed.) *Groundwater Management: Supply Dominated Focus of Government and NGO Efforts*, Monograph, VIKSAT, Nehru Foundation for Development, Ahmedabad.

Rangachari, R.; Sengupta, N.; Iyer, R.R.; Banergy, P.; Singh, S. 2000. Large Dams: India’s Experience, Final Report, prepared for the World Commission on Dams, Cape Town, South Africa, Secretariat of World Commission on Dams.

Rockström, J.; Barron, J.; Fox, P. 2003. Water productivity in rain-fed agriculture: Challenges and opportunities for smallholder farmers in drought-prone tropical ecosystems. In Jacob Kijne and others (Eds.) *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, Comprehensive Assessment of Water Management in Agriculture. UK: CABI Publishing in Association with International Water Management Institute.

Sahuquillo, A. 1985. Groundwater in Water Resource Planning: Conjunctive Use, *Water International*, 10 (1985) 57-63.

Sakthivadivel, R.; Fernando, N.; Brewer, J. 1997. *Rehabilitation Planning for Small Tanks in Cascades: A Methodology Based on Rapid Assessment*, Research Report 13, International Irrigation Management Institute, Colombo, Sri Lanka.

Seckler, D. J. 1996. *The New Era of Water Resources Management: From Dry to Wet Water Savings*, Research Report # 1, International Irrigation Management Institute, Colombo, Sri Lanka.

Shah, T. 2001. Wells and Welfare in Ganga Basin: Public Policy and Private Initiative in Eastern Uttar Pradesh, India, Research Report 54, International Water Management Institute, Colombo, Sri Lanka

Shah, T. 2002. Decentralized Water Harvesting and Groundwater Recharge: Can these Save Saurashtra and Kachchh from Desiccation, paper presented at the annual partners’ meet of the IWMI-Tata Water Policy Research Programme, Anand, February 19-20.

Sharma, A. 2002. Does Water Harvesting Help in Water-Scarce Regions? A Case Study of Two Villages in Alwar, Rajasthan, paper presented at the annual partners’ meet of the IWMI-Tata Water Policy Research Programme, Anand, February 19-20.

Sivapalan, M.; Kalma, J.D. 1995. Scale problems in hydrology: Contributions of the Robertson Workshop, *Hydrological Processes*, 9 (3-4): 1995.

Verghese, B. G. 2001. Sardar Sarovar Project Revalidated by Supreme Court, *International Journal of Water Resources Development*, Vol. 17 (1), 79-88.

Varghese, B. G. 2002. Water and Energy for Future India, paper presented at the International Regional Symposium on Water for Human Survival, 26-29, November, 2002, Hotel Taj Residency, New Delhi.

Wood, E. F.; Sivapalan, M.; Beven, K. 1990. Similarity and scale in catchment storm response. *Rev. Geophysics*, 28, 1-18.

Zhu, Z.; Giordano, M.; Cai, X.; Molden, D. 2004. Yellow River Basin Water Accounting, International Water Management Institute, Colombo, Sri Lanka.

Decentralized Artificial Recharge Movements in India: Potential and Issues

R. Sakthivadivel
IWMI Senior Fellow

Introduction

Rainwater harvesting (concentrating runoff from watersheds for beneficial use) was practiced in the arid- and semi-arid tracts of India as early as the sixth century. Encompassing any practice that collects runoff for productive purposes, rainwater harvesting includes three components: 1) a watershed area to produce runoff; 2) a storage facility (soil profile, surface reservoirs or groundwater aquifers); and, 3) a target area to beneficially use the water (agriculture, domestic or industry). The classification varies depending on the spatial scale of the runoff collection, from in-situ practices managing rain on the farmland (often defined as water conservation) to external systems collecting runoff from watersheds outside the cultivated area. Rainwater harvesting practices are further classified by storage strategies from direct runoff concentration in the soil to collection and storage of water in structures (surface, subsurface tanks, and small dams). In many decentralized artificial recharging activities, rainwater harvesting is a part and parcel of the decentralized artificial recharge.

In many parts of India, especially in the arid- and semi-arid regions, due to variations in the monsoon and scarcity of surface water, dependence on groundwater resources has increased tremendously in recent years. Easy availability of credit from financial institutions for sinking tube wells coupled with provision of subsidized/ free electricity for pumping in many states has exacerbated the increased extraction of groundwater. On the other hand, rapid urbanization and land use changes has decreased drastically the infiltration rate into the soil and has diminished the natural recharging of aquifers by rainfall. These factors have contributed to lowering the water table so much that many dug wells and tubewells are decreasing now in their yield and ultimately drying up. The situation becomes more precarious during summer, when most of the yield of dug wells and shallow tubewells either reduces considerably or dries up. The drinking water crisis, which is prevalent in most of the villages during the summer, imposes serious health hazards to the rural masses and, is responsible for the loss of a huge livestock population for want of drinking water and fodder (Shah 1998).

Artificial recharging is the planned, human activity of augmenting the amount of groundwater available through works designed to increase the natural replenishment or percolation of surface waters into groundwater aquifers, resulting in a corresponding increase in the amount of groundwater available for abstraction. Augmentation of groundwater resources through artificial recharging of aquifers, which supplements the natural process of recharging, has become relevant in situations witnessed in India, where the rainfall is seasonal (monsoon) and is not spread uniformly across the country, and the quantum of natural recharge is inadequate to meet the increasing demand of groundwater resources. The artificial recharging of groundwater has been taken up as one of the corrective measures on the supply side to compensate for this overexploitation and to retard the drying of tubewells. The artificial recharging of shallow aquifers to supplement groundwater is not new to this country. It has been in vogue from time immemorial in the hard-rock, semi arid regions of India, where artificial recharging co-existed with the water conservation of monsoon rains through innumerable small water-holding structures (called dug wells) and dugout ponds (called '*ooranies'*).

This paper looks at the historical evolution of the groundwater recharge movement; how it has gathered momentum; who promoted these activities; and what it has achieved to-date. The paper highlights the potential of decentralized groundwater recharging as well as the associated issues. At the end of the paper, a road map for long-term and near-term strategy for artificial recharging is suggested.

The next section briefly presents the progression of the use of artificial recharge in India.

Progression of Artificial Recharge Movement in India

Artificial recharge, one of the oldest activities undertaken in India to conserve rainwater both on the ground and underground, is as old as the irrigated agriculture in the arid- and semi-arid regions. In the olden days, the recharge movement initiated by the local communities was aided and supported by the kings; chieftains; philanthropists and by those who valued water and practiced conservation. There are numerous examples and stone inscriptions from as early as 600 A.D. citing that ancient kings and other benevolent persons considered the construction of '*ooranies'*, as one of their bounden duties in order to collect rainwater and use it to recharge wells constructed within or outside '*ooranies'* , to serve as drinking water sources. Even today, thousands of such structures exist and are in use for multiple purposes in the southern coastal towns and villages of Tamil Nadu, where underground water is saline (DHAN Foundation 2002).

More than 500,000 tanks and ponds—big and small, are dotted all over the country and more so in the peninsular India. These tanks were constructed thousands of years ago to cater for multiple uses, including irrigated agriculture, livestock and for human use such as drinking, bathing, and washing. The command area of these tanks has numerous shallow dug wells, which are recharged with tank water and are used for augmenting the tank water. Many drinking water wells located within the tank bed and/or on the tank bund are artificially recharged from the tank into these wells to provide a clean water supply throughout the year with natural filtering (DHAN Foundation 2002).

In traditionally-managed tank irrigation systems, when the supply of water to the tank is insufficient to raise a crop by gravity flow from the tank, it is not uncommon for the village community to decide to close all tank sluices and allow the tank to act as a percolation tank to recharge the wells in the command area. Subsequently, the recharged water is shared by the beneficiary farmers. This has been done to distribute the limited water to the crops without any line losses due to the gravity flow. This practice is in vogue even today in many traditionally-managed irrigation systems. With the water supply to many tanks dwindling for various reasons, this practice of converting irrigation tanks to percolation tanks to artificially recharge the wells in the command is increasing day by day. This practice has become a movement by itself, and even certain state governments such as Karnataka are encouraging this practice through the enactment of law and enforcement (Sakthivadivel and Gomathinayagam 2004).

Harvesting roof-water and storing it underground in tanks is a very common phenomenon in many Indian states, which are experiencing acute shortages of drinking water supplies. Similarly, pumping induced recharge water from wells located near water storage structures like tanks, irrigation canals and river courses, and transporting it to a long distance through pipelines for irrigation is a common sight in many water-deficient basins. These activities, which originated spontaneously and mostly due to necessity, are a movement by themselves. Further details on traditional water harvesting and recharge structures can be had from a publication entitled 'Dying Wisdom' by Anil Agrawal and Sunita Narain (2001).

The spread of Artificial Recharge Movement in India (ARMI) can be broadly classified under four phases. The first phase relates to the period before the green revolution when limited exploitation of groundwater was taking place i.e., before 1960; the second is the period between 1960 and 1990, where intense groundwater exploitation took place with signs of over exploitation; the third is the period from 1990 to -date, when water scarcity is increasing alarmingly and the groundwater level is declining in certain pockets of India; and the fourth phase is of recent innovation when large-scale pumping equipment and pipelines become available and affordable.

The first phase is the one when traditional water harvesting methods were given impetus through unorganized yet spontaneous movement by the local communities, aided by kings and benevolent persons to meet the local requirement at a time of crisis. During this period, there was very little knowledge-based input from the government, non-government organizations and the scientific community to provide assistance for understanding and putting into practice a systematic way of artificial recharging, and up-scaling. Yet, the local community used their intimate knowledge of terrain, topography and hydrogeology of the area to construct and operate successful artificial recharge structures, some of which have managed to survive even to -date. In this phase, there was little application of science related to artificial recharging; most of the experiences were based on local knowledge and perceived wisdom. Very little understanding existed about the consequences of and the knowledge required for artificial recharging of underground aquifers.

The second phase coincides with the period of large-scale extraction of groundwater resulting in many aquifer systems showing signs of overexploitation, especially in the arid- and semi-arid regions. During this phase, the curriculum relating to hydrogeology and groundwater engineering were introduced in many universities and the science of groundwater hydrology was better understood. Both the public and the government had started realizing the importance of recharging aquifers to arrest the decline in groundwater and maintain the required groundwater levels. As a consequence, pilot studies of artificial recharging of aquifers were carried out by a number of agencies including Central and State Ground Water Boards, Water Supply and Drainage Boards, Research Institutes such as National Geophysical Research Institute (NGRI), Physical Research Laboratory (PRL), National Environmental Engineering Research Institute (NEERI), agricultural and other academic institutions, and non- governmental organizations such as Centre for Science and Environment (CSE).

Pilot studies of different kinds have been carried out and the technical feasibility of artificial recharging and recovery of recharged water have been established. During this period, two important events with respect to artificial recharging took place that are of relevance to the movement. One is the synthesis of research and development works carried out in India in artificial recharging by a team of experts under the Rajiv Gandhi National Drinking Water Mission, constituted by the Ministry of Rural Areas and Development, Government of India, New Delhi. . The second is the effort provided by the Indian Standard Organization (ISO) to bring out technical guidelines and specifications for artificial recharging. These have given impetus for further experimentation on artificial recharging.

The third phase is the current phase where water scarcity, continuous droughts in certain pockets of India and the continuously declining groundwater levels in many parts of India have forced both the public and the government to become aware and take up artificial recharging on a war footing. Three major events that took place during this period are significant to the artificial recharge movement in India. One is the spontaneous uprising and co-operation from the public supported by religious leaders, philanthropists, and committed individuals to take up artificial recharging through dug and bore wells, check dams and percolation ponds, followed by the government joining hands with the local community in implementing such schemes on a mass scale (Shah 1998). The second is the action taken by a state government such as Tamil Nadu, in promulgating the groundwater regulation act pertaining to the metropolitan area and ordering the community to implement rainwater harvesting schemes and artificial recharging on a compulsory basis in the metropolitan area. The third event relates to the awareness created among the public by the non-governmental organizations such as the Centre for Science and Environment and Tarun Bharat Sangh and the media exposure to the importance of artificial recharging.

The fourth is the recent increasing trend of abstraction of induced recharge witnessed in many gravity irrigation systems in states like Tamil Nadu and Gujarat. Given the increase in water-scarcity faced in many irrigation systems, the availability of large-scale pumping machinery at affordable prices and subsidized power have led many enterprising farmers to resort to wells near the storage reservoirs, and on canal and riverine courses to create induced recharge in their wells. The induced recharge water is then transported through pipe lines to many km away from the pumping site to irrigate non-command areas with orchards and other high-value crops using drip and sprinklers. This practice of pumping induced recharge water outside the command area has had a very negative effect on managing large irrigation systems because of the siphoning of a considerable quantity of water to areas not originally included in the command. This occurs more so in the years when there is an inadequate supply of water to the reservoirs as well as in the drought years. This is a spontaneous movement, which is spreading like wild fire; if it is not controlled and regulated, many surface irrigation systems will suffer their natural death in the very near future. (Neelakantan 2003).

Artificial Recharge Methods

The following artificial recharge methods are in vogue:

1. Direct methods in which water from surface sources are conveyed or stored in- situ at places above the aquifer areas, where the water is made to percolate and recharge the groundwater.

2. Indirect methods in which the transfer of surface water is induced as a consequence of human activity and is effected by locating the groundwater abstraction wells near influent streams. Another type of indirect recharge is from the seepage of streams or canals or lake-beds and return flow from irrigation.

3. The combination of the above two methods, which are widely used to meet the topography and terrain condition.

In areas where rainfall is scarce and drought frequency is high, artificial recharging of rainwater is accomplished by employing an integrated series of techniques, which, for example, can include damming the gullies of minor streams, constructing subsurface dikes and/or percolation tanks along their tributaries, contour bunding and trenching on slopes, placing farm ponds in the foothills, and wherever possible, installing check dams-cum- minor irrigation dams on the main stream courses. Terracing and forestation of hillsides, which help to retain runoff and increase infiltration, may also form part of an integrated basin-scale water resources development plan. An important factor to be considered while designing an artificial recharge structure is the consideration of their stability during high flows and the minimization of accumulation of silt and organic matter within the structure.

In many parts of India, rural drinking water supply programs often witness shortages of supply from bore wells because of the increase in groundwater use for irrigation from bore holes in and around the drinking water bores. Enhancement of recharge to the groundwater has, therefore, become mandatory in areas where groundwater is the only source of drinking water supply. The methodology of Artificial Recharge and Retrieval (ARR) can profitably be used for recharging a well during the monsoon and using it for drinking water during the summer months. Two or three such wells may be declared as sanctuary wells for each village and the ARR scheme may be implemented (Muralidharan and Athavale 1998).

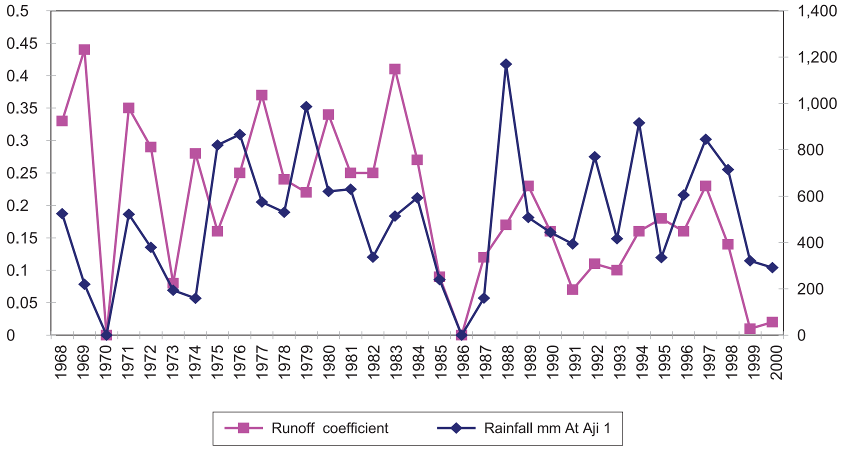
Impacts of Artificial Recharging

Two typical contrasting case studies to illustrate decentralized artificial recharging on the upstream and downstream impact and local level benefits accrued from recharging are illustrated here:

Upstream-Downstream Impact of Artificial Recharging

Upstream development of water harvesting structures in a basin/watershed context affects the inflow to the downstream storage impoundment. There are few who think that upstream impounding storage volume in micro recharge structures is only a very small fraction of the total massive volume of rainfall falling on a vast catchment and, as such, may not have a perceptible impact on the downstream flow. But, there is another school of thought arguing upstream development will have a marked effect given the innumerable number of check structures coming up in the catchment. Also, in many catchments experiencing marked inter- and intra-annual variation in rainfall, especially when the watershed is a closed one, supply to the downstream reservoirs is very much affected by the upstream development of artificial recharge structures. This point is brought out by the following example.

Figure 1. Rainfall and runoff variations in Aji1 watershed from 1968-2000.



Aji1 watershed in Saurastra is a water-scarce and closed subbasin with a very high variation of annual rainfall ranging from 200 mm to 1,100 mm. Aji1 reservoir is a water supply reservoir to the city of Rajkot, located at the tail- end of the Aji1 watershed. The flow to the reservoir was on the decline, especially after 1985 due to the construction of thousands of check dams and percolation ponds within the Aji1 watershed. The construction of these small water conservation and recharge structures is a result of a recharge movement initiated initially by Shri Panduranga Athvale, a religious guru of the Saurashtra people and later supported by the Government of Gujarat.

In order to verify whether there is a downstream impact due to the upstream development of check dams and percolation ponds constructed for recharging the groundwater aquifer, rainfall and inflow data to the Aji1 reservoir was collected for the years 1968-2000 and a simple analysis was made to compute the runoff coefficient. The computed coefficient along with rainfall is plotted in Figure 1. The x-axis represents the years starting from 1968 while the y-axis represents annual rainfall and runoff coefficients. As seen in the figure, the contribution to the reservoir storage was significantly reduced after 1985. The runoff coefficient was fairly high up to 1985 and thereafter it has reduced considerably. Nevertheless, the rainfall remained more or less the same before and after 1985. The average reduction in the runoff coefficient after 1985, which is almost 100 % of its original value, indicates the extent of impact of the upstream water harvesting structures on the downstream reservoir. Water harvesting in the upstream part of the watershed has definitely affected the downstream drinking water use of the Rajkot Municipality. This downstream impact on storage reservoir due to the upstream development of water harvesting structures need to be kept in mind while designing water harvesting structures for artificial recharge. Hence, before such structures are constructed, water accounting for the subbasin should be carried out (Molden and Sakthivadivel 1999).

Impact Evaluation of Check Dams

The year 2000 was an unprecedented drought year in the State of Gujarat. The water crisis in that year had created an intense awakening among the people of the Saurashtra and Kutch regions about the importance of artificial recharging of groundwater. Several social workers and service-oriented nongovernmental organizations (NGOs) had undertaken numerous water conservation projects in these regions by collecting voluntary contributions from the people for harvesting rainwater to recharge groundwater, which can be utilized for drinking and agricultural purposes. Their efforts and results have been overwhelmingly successful. As a result of these efforts, under Sardar Patel Participatory Water Conservation Program (SPPWCP), the Government of Gujarat had invested over Rs.1,180 (US$28) million in the construction of 10,708 check dams distributed over Saurashtra, Kutch, Ahmedabad and the Sabarkantha regions. These works were carried out with direct and indirect financial participation of beneficiaries, who contributed up to 40 % of the estimated cost, and the government paying the balance 60 %. The entire responsibility of managing the quality of construction work was undertaken by the beneficiary group/NGO.

An independent evaluation of the check dams in Gujarat was carried out in 2002 by the Indian Institute of Management (IIM), Ahmedabad, covering vital aspects like: a) total evaluation of the project; b) advantages of people's participation; c) benefits in agricultural production; d) drinking water supply; e) availability of fodder; and, f) socioeconomic cost benefits (Shingi and Asopa 2002).

Following the analysis of the survey data for over one hundred check dams, and after personal visits by the evaluation team to a large number of other check dams, and talking to more than 500 farmers, the team concluded that:

1. Localized rainwater harvesting systems in the form of check dams in Saurashtra contain a proven solution to water crisis by recharging rainfall runoff into an underground aquifer, offering a decentralized drought-proofing system, and allowing for the people's involvement in critical water management tasks, with simple, local skill based, cost-effective, and environmental friendly technologies.

2. The rainwater harvesting efforts initiated with the people's participation and support from SPPWCP should be re-launched and implemented on a larger scale.

3. The 60:40 scheme (60 % by government and 40 % by beneficiary) has six major features capable of attracting donor investments. These features include: i) rainwater harvesting is an ecologically sound proposition to recharge depleting groundwater sources; ii) the scheme is highly participatory as people contribute to the extent of 40 % of the cost by way of labor, equipment, and/or money; iii) the scheme is highly gender sensitive as women are the major beneficiaries of the alleviation of drinking water and livestock feed problems; iv) the project does not replace or endanger human and wildlife habitats; v) the scheme focuses on equitably using renewable resource like rainwater; and vi) the proposition is economically and financially very sound with a short pay back period.

The 60:40 scheme has been and should continue to remain as the people's program. Without the people's participation, the scheme is unlikely to survive. It is only the people's involvement that would ensure critical components like: a) quality of works; b) preventing the entry of undesirable contractor's into partnerships with the government; c) sustainable maintenance and supervision; d) speed of implementation; e) ingenuity and innovative way of implementation; and f) cost-efficient technical guidance, prompt clearing of bills and respectful encouragement, which are the kind of inputs that people need the most.

The Role of Artificial Recharge in the Overall Water Requirement of the Country in 2050

The total water resource availability in 2050 for high population growth is estimated by Gupta and Deshpande (2004) as given in Table 1.

Table 1. Water resources availability for 2050 (km^3)—(Based on low and high population growth).

Water available during 2001	Water required during 2050	Anticipated water deficit	Possible measures to meet the deficit				
			EUSW+GW in excess of 1998	Recyclable waste-water	Irrigation return flow	RAGWR	Water availability
500	973-1,450	473-950	SW = 420 GW = 202 Total = 550**	103-177*	33-133	125	1,311-1,485

Source: S.K.Gupta and R.D. Despande

Notes: * Ignored water quality issues
** After considering 17 % decline in storage for surface sedimentation

Table 1 shows that the largest increase of 550 km^3 per year in water supply comes from harnessing economically utilizable surface water (EUSW) from the conventional runoff of the river schemes and the untapped groundwater potential, followed by the return flow (RF) by developing full irrigation potential. It can also be noted from Table 1 that without the contribution from retrievable artificial groundwater recharge (RAGWR) and recyclable wastewater, the projected water requirement cannot be met, necessitating inter-basin transfer.

Cost of Artificial Recharging

For a wider adoption of artificial recharging and use of a particular method, the cost of recharge and recovery of various artificial recharge methods is an important parameter that needs to be determined. Full-scale artificial recharge operations in India are limited and as a consequence, cost information from such operations is incomplete. The cost of recharge schemes, in general, depend upon the degree of treatment of the source water, the distance over which the source water must be transported, and the stability of recharge structures and resistance to siltation and/or clogging. In general, the costs of construction and costs of operation of the recharge structures, except in the case of injection wells in alluvial areas, are reasonable. The comparative cost of recharged water per 1,000 m^3 in such cases works out to Rs. 40 to 120. On the other hand, the cost of using recharged groundwater for domestic water supply purposes, varying from Rs. 2 to 6 per person per year is very reasonable, especially in areas where there is a shortage of water (CGWB 1984). The initial investment and operating costs are many times less than those required for supplying potable water using tankers. Combining technologies can also result in cost savings. For example, in Maharashtra, the capital cost of combining a connector well and tank into a hybrid scheme was about Rs 40,000 (the cost of borehole) compared to the cost of a comparable percolation tank system needed to achieve a similar degree of recharge, which is estimated to be about Rs. 4,800,000. Table 2 summarizes the estimated costs of various artificial recharge methods:

Table 2. Economics of various artificial recharge methods.

Artificial recharge structure type	Capital cost (Rs.1,000m^3) of recharge structure	Operational cost (Rs.1,000m^3/ year)
Injection well (alluvial area)	Rs. 23,000	850
Injection well (hard-rock)	80	200
Spreading channel (alluvial area)	320	800
Recharge pit (alluvial area)	21,000	80
Recharge pond or percolation pond (alluvial area)	40	40
Percolation tank (hard-rock area)	200	40
Check dam	40	40

Source: UNEP International Environment Centre (2004)

Research and Development in Artificial Recharging

The problems associated with artificial recharging include aspects such as recovery efficiency, cost-effectiveness, contamination risks due to the injection of poor quality recharge water, clogging of aquifers, upstream-downstream impact, inequity in water distribution and a lack of knowledge about the long-term implications of the recharge process.

In India, various artificial recharge experiments have been carried out by different organizations, and have established the technical feasibility of the artificial recharge of unconfined, semi-confined and confined aquifer systems. However, the most important and somewhat elusive issue in determining the utility of this technology is the economic, institutional and environmental aspects of the artificial recharge. Experiences with full scale artificial recharge operations in India are limited and as a consequence, cost information from such operations is incomplete. Moreover, costs are a function of availability of water source, conveyance facilities, civil constructions, land, and groundwater pumping and monitoring facilities (CGWB 1994). Therefore, research on cost-related to artificial recharging needs to be taken up.

The importance of proper planning of groundwater recharge, conservation, optimum utilization and management of the recharged water is given least attention by the policymakers, managers and users of this precious resource. Proper harnessing of surface water through artificial recharging and judicious husbanding of recharged water assume greater significance in the present state of groundwater resources development and management in India. Therefore, the economic, managerial and institutional aspects of artificial recharge projects need to be studied further.

The studies on artificial recharge techniques are mostly site-specific and descriptive in nature, which gives little insight into the potential success of implementing this technology in other locations. Thus, there is a need for further research and development in artificial recharge techniques for a variety of conditions.

A Road-map for Long-term and Short-term Strategy for Artificial Recharge

To meet the growing requirements of water for various activities, it is imperative not only to develop the new water sources but also necessary to conserve, recycle and reuse water wherever possible. It is estimated that by prudent artificial recharge schemes and wastewater recycling, about 25 % of India's water requirements in 2050 can be met. Both these measures provide water at local scale, where people live and engage in productive activities. In the short-term, rainwater harvesting and artificial groundwater recharge where people and the community can directly participate, as in the 'recharge movement in Gujarat', must be given thrust and focus by all who are concerned with India's water. The gestation period for such projects can be a few months to a few years and because of the distributed nature of this activity, it is only through the involvement of local communities that sustainable groundwater augmentation can take place. This strategy is also evident from the importance given by the Government of India in water conservation and use through watershed development.

In the many densely populated areas of western and southern India, a rapid development in intensification of well-irrigation is taking place where rainfall precipitation is the only source of groundwater recharge. The number of groundwater wells has increased from less than 100,000 in 1960 to nearly 12 million today (Shah et al. 2004). With depleting aquifers and erratic rainfall, local communities as well as the government are turning to constructing local water harvesting and recharge structures at a massive scale with the primary objective of increasing groundwater availability for improved drinking water security, drought-proofing and protecting rural livelihood. Efforts should be undertaken to effectively use the existing structures as artificial recharge structures instead of constructing new structures.

There are some specific issues relating to decentralized artificial recharging, which need to be kept in mind while undertaking this activity:

1. Blue water investments are located mainly downstream in watersheds and basins, because they depend on the concentration of large volumes of stable runoff (in lakes and rivers). Large-scale irrigation, therefore, benefits predominantly the downstream communities, while water harvesting offers an appropriate water management complement for agriculture for wide spatial coverage across watersheds and basins. Capturing local runoff upstream in water harvesting systems addresses problems of frequent drought and prevailing poverty in upper watersheds.

2. Every increase in water used in agriculture will affect water availability for other uses, both for direct human use (water supply) and for eco-system use (terrestrial and aquatic eco-systems). In over-committed watersheds, upgrading rain-fed agriculture through investments in water harvesting and artificial recharging systems may result in a severe water trade-off with downstream users and eco-systems. Proper water balance and water accounting need to be carried out before initiating a recharge project.

3. Investing in water management through water harvesting and artificial recharge in rain-fed agriculture can have positive environmental impacts on other eco-systems as a result of reduced land degradation and improvements in water quality downstream.

4. Capturing water close to the source (where the raindrop hits the ground) as is common in upstream water harvesting systems, reduces evaporative losses of blue water during its journey from field to watershed to river basins. Basin-wide gains are possible from investments in upstream water harvesting and artificial recharging in rain-fed agricultural systems.

5. Groundwater recharge schemes should continue to remain as the people's programs. Without the people's participation, the program is unlikely to survive. It is only the people's involvement in the scheme that would ensure critical components like quality of works; preventing undesirable contractors' entry into partnership with the government; sustainable maintenance and supervision; speed of implementation and cost-efficiencies. Intensive efforts should be made to elicit support from: reputed NGOs; spiritual bodies; charitable organizations; donors; industrial houses; and spirited individuals who have unquestionable interest in the region and the well-being of the people, to promote, participate in and provide for the scheme. The involvement of the Panchayat administration up to district level is also necessary. An aggressive campaign approach is needed to educate and motivate rural collectivities using promotion tools like Jal-Yatra as was done highly effectively in Saurashtra.

References

Agrawal, A.; Narain, S. 2001. Dying Wisdom. New Delhi, India: Centre for Science and Environment,

Central Ground Water Board (CGWB). 1994. Manual on Artificial Recharge of Groundwater. Technical Series: Monograph No.3. Ministry of Water Resources, Government of India. pp 215.

DHAN Foundation. 2002. Revisiting Tanks in India, National Seminar on Conservation and Development of Tanks. New Delhi, India.

Gupta, S. K.; Deshpande, R.D. 2004. Water for India in 2050: First-order assessment of available options. Review Paper. *Current Science* 86 (9):1216- 1224.

Molden, D.; Sakthivadivel, R. 1999. Water accounting to assess use and productivity of water. *International Journal of Water Resources Development*. *Special Double Issue* 15 (1&2): 55-71.

Neelakantan, S. 2003. *A gossipmonger's revisit to Chettipalayam*. Working Paper No. 142. Chnnai, India: Madras Institute of Development Studies.

Muralidharan, D.; Athavale, R.N. 1998. Base paper on artificial recharge in India. National Geophysical Research Institute. Hyderabad, India: CSRI.

Sakthivadivel, R. Gomathinayagam, P. 2004. Case Studies of locally managed tank systems in Karnataka, Andhrapradesh, Gujarat, Madhyapradesh, Gujarat, Orissa, and Maharashtra; Report submitted to IWMI-Tata Policy Program, Anand, India. pp 246.

Shah, T. 1998. The Deepening Divide: Diverse Responses to the Challenge of Groundwater Depletion in Gujarat. Anand, India: Policy School.

Shingi, P.M.; Asopa, V.N. 2002.Independent Evaluation of Check Dams in Gujarat: Strategies and Impacts. Executive Summary. Centre for Management in Agriculture, Indian Institute of Management. Ahemedabad, India: Indian Institute of Management.

Real-time Co-management of Electricity and Groundwater: An Assessment of Gujarat's Pioneering 'Jyotirgram' Scheme

Tushaar Shah and Shilp Verma
International Water Management Institute, Anand, India

Historical Backdrop

Despite massive public investments in canal irrigation, Gujarat agriculture has come to depend heavily on irrigation with wells and tubewells. During the 1950s and 1960s, farmers used mostly diesel engines to pump groundwater. However, as rural electrification progressed, they began switching to submersible electric pumps, especially as diesel pumps are unable to **chase** declining water levels. Major expansion in the use of electric pumps occurred during the late 1980s as the Gujarat Electricity Board (GEB) changed to flat tariffs linked to the horse power of pumps. Until 1988, farmers were charged based on the metered use of electricity. However, as electric tubewells increased to hundreds of thousands, rampant corruption began to plague meter reading and billing. Farmers also complained about the tyranny and arbitrariness of the GEB's meter readers.

The new flat tariff system introduced in 1988 produced major beneficial productivity and equity impacts on smallholder irrigation. Since the marginal cost of electricity to tubewell owners was zero, they were induced to aggressively sell water to their neighbors, typically marginal farmers and share-croppers unable to afford their own tubewells. Competition among sellers pared down the prices of pump irrigation service in local informal water markets, which greatly benefited the poor. Flat tariff also expanded groundwater irrigation, increased the utilization of tubewells and reduced the GEB's cost of metering and billing over electric tubewell connections. However, the ill-effects of flat tariff were serious too. For example, it led to groundwater over-exploitation and it meant that farmers had to pay electricity charges even during the monsoon when they used little irrigation. Most seriously, flat tariff became sticky and gradually increased GEB's losses in supplying power to agriculture. These could have been controlled if the GEB had gradually raised flat tariff in tandem with the increase in power consumption in agriculture. However, farmer lobbies strongly opposed government efforts to raise flat tariff, leading to mounting losses to the GEB on account of agriculture (Joshi et al. 2005).

Given the circumstances, the government had no option but to gradually reduce the power supply to agriculture. During the 1980s, farmers got 18-20 hours of 3-phase electricity/day; this came down to 10-12 hours by the turn of the millennium. Moreover, the quality and timing of the power supply deteriorated, too. Power supply came with low voltage, often during the nights and with frequent trippings damaging motors. The poor and inadequate supply of power to agriculture became the key issue in Gujarat's mass politics (Shah et. al. 2003*)*.

The GEB also found it difficult to ration the power supply to tubewells without hitting the power supply to domestic and other rural uses. Normally, single-phase power that can run domestic appliances was provided 24 hours, but 3-phase power required to operate tubewells, grain mills and other heavy equipment was restricted to 10-12 hours. To beat this system, farmers everywhere in Gujarat began using capacitors (locally called *tota)* to convert two or even single phase power into 3-phase power to run their tubewells. This reduced the voltage downstream which affected the village community, while tubewells continued to operate unhindered for 18-20 hours/day. The rural society and its non-farm economy were held hostage by the burgeoning groundwater economy of Gujarat. Power engineers considered capacitors to be the gateway to an improved power factor (pf) (PRAYAS 2004),[1] but in rural Gujarat, farmers turned these into an instrument for power-theft.

It was commonly argued that the way out of this imbroglio was to meter tubewells, improve the amount and quality of power supplied to farmers, and charge metered tariffs. Shah et al. (2003) had, however, argued that though correct in principle, taking this route in present conditions would resurrect the logistical problems of metering, for the resolving of which Gujarat (and other Indian states) had changed to flat tariff in the first place. They argued that this would attract massive farmer opposition, and, if the experience in other states was any indication, imply political hara-kiri for any leader who championed it. Instead, Shah et al (2003) argued for a second-best solution of separating feeders supplying power to tubewells from other rural feeders and undertaking 'intelligent rationing' of power supply to tubewells in a way that emulates a high-performing canal irrigation system. In particular, Shah et al. (2003) recommended that: (a) flat tariff on farm power use should be raised gradually to approach the average cost of power consumed by a tubewell; (b) low-cost off-peak night power should be judiciously used to keep the average cost of farm power supply low; (c) intelligent scheduling and management of 'rationed' power supply to the farm sector should be the central element of the strategy of effective co-management of groundwater and electricity use in agriculture. Shah et al. (2003) anticipated that "Farmers will no doubt resist such rationing of power supply, however, their resistance can be reduced through proactive and intelligent supply management by (a) enhancing the 'predictability' and 'reliability' of power supply; (b) improving the 'quality' in terms of voltage and frequency, and minimizing trippings; and (c) better matching of power supply with peak periods of moisture stress."

During 2001-2, this proposal, henceforth referred to as the IWMI proposal, was presented and discussed in several workshops and conferences in Gujarat as well as in other states. In Gujarat, the IWMI proposal (Shah et al. 2003) was shared with the Minister of Power, Gujarat Electricity Regulatory Authority as well as the Chairman of Gujarat Electricity Board. The IWMI proposal seemed timely since around then, Gujarat was in the midst of a major power sector

---

[1] Motors running irrigation pumps have a pf of 0.7-0.8, which the use of a capacitor can raise to 1. A 100 kVA transformer can be connected to 26 motors of 5 hp with capacitors instead of 18 without getting overloaded. Capacitors improve the voltage and reduce the load on the transformer and, in general, curtail power loss in distribution.

restructuring exercise with a loan from the Asian Development Bank (ADB). Power generation and transmission/ distribution were unbundled, with the latter task taken over by five regional power distribution companies, each mandated to operate on commercial principles. The key impediment in the exercise was farm power. The ADB's answer was metering of farm power supply. But in view of stiff farmer opposition, the Government of Gujarat had to go slow on this move and, as a result, the ADB suspended the release of the loan installment. Instead of metering tubewells, however, in September 2003, the Government of Gujarat launched the *Jyotirgram Yojana*, which included some of the key recommendations of the IWMI proposal but also went far beyond them, and unleashed a new wave of rural development in the state.

Jyotirgram Scheme

Jyotirgram Scheme (JGS) was launched initially in eight districts in Gujarat on a pilot basis, but by November, 2004, it was extended to the entire state. By 2006 over 90 % of Gujarat's 18,000 villages were covered under the JGS. This was a massive operation,[2] which involved laying a parallel rural transmission network across the state at an investment of Rs.1, 170 crores. Feeders supplying an agricultural connection were bifurcated from those supplying to commercial and residential connections at the sub-station itself. Meters on distribution transformer centers were also installed on both sides of feeders to improve accuracy in energy accounting (MGVCL 2007).

Figure 1a. Electricity network before JGS.

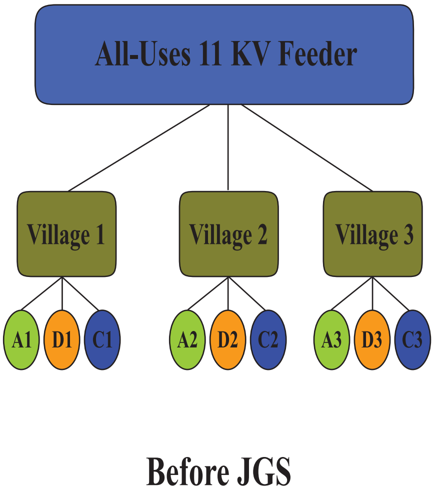
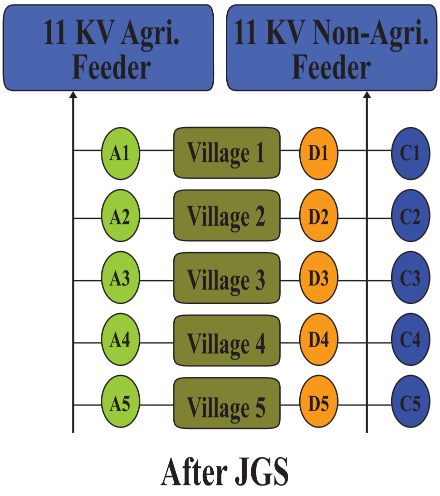


Figure 1b. Electricity network after JGS.



---

[2] It involved total rewiring of rural Gujarat. 48,852 km of high-tension lines and 7,119 km of low-tension wires were added. 12,621 new transformer centers were installed. 1.2 million new electricity poles were used. 1,470 specially designed transformers were installed. 182,000 km of electricity conductors and 610,000 km of low- tension PVC cables were used. 30,000 tonnes of steel products were used.

Pre-JGS, at the lowest level of 11KV feeders served a group of 2-5 villages wherein all connections (domestic, agricultural as well as commercial) were through this feeder (see Figure 1a). Post-JGS, however, the feeders were bifurcated into agricultural and non-agricultural feeders (see Figure 1b). This meant that certain feeders only served farm consumers and connections while the rest served the domestic and commercial customers. Meters on agri-feeders were meant to identify the source of any 'significantly-greater-than-expected' demand. Rural Gujarat thus rewired, and two changes occurred: (a) the villages began to be provided with a 24-hour power supply for domestic use, schools, hospitals and village industries; (b) farmers began getting 8 hours of daily power supply at full voltage on a pre-announced schedule. Every village is to get agricultural power during the day and night in alternate weeks that are pre-announced.

JGS is held out as a win-win solution for everyone involved. Studies by IRMA as well as Ahmedabad based Centre for Environment Planning and Technology (CEPT) have narrated a myriad of ways in which JGS has improved village life. Both these studies, however, glossed over the new dynamic that the JGS has catalyzed in Gujarat's agriculture. In early 2007, IWMI undertook a quick assessment of the impacts of the *Jyotirgram* Scheme (JGS) in 55 villages spread over 10 districts with the help of local researchers. The study laid particular emphasis on its impacts on Gujarat's groundwater economy. The individual case studies developed by local researchers can be obtained from t.shah@cgiar.org. This paper synthesizes these case studies to evolve a preliminary assessment of JGS impacts and its lessons for the co-management of electricity and groundwater. Our findings on JGS impacts on the quality of rural life, and on the non-farm economy are in total agreement with the highly positive assessment of IRMA and CEPT studies and, as such, we deal with these in summary form but discuss in greater detail the agrarian impacts of JGS that have so far remained unexplored.

Jyotirgram Impacts on the Quality of Rural Life

Today, rural Gujarat enjoys a 24-hour power supply of and at a quality that is unrivalled by rural areas elsewhere in India because of the JGS. All our case studies uniformly attested that for common villagers of the state, JGS has resulted in a tremendous improvement in the quality of daily life. Power cuts, which were endemic, have become almost non-existent, and so have voltage fluctuations. For a long time before the JGS, rural life as well as the economy were afflicted with an unpredictable, frequently interrupted power supply that was also of low quality and that made it impossible for people to organize their daily chores or economic activity. Women were constantly worried about securing domestic water supply; livestock keepers had to time milking and feeding of cattle according to the power supply; school teachers and students were anxious about power outages while using laboratory equipments, computers, television sets etc. For instance, during Gujarat's hot summer, the inability to operate fans made the afternoon heat insufferable in schools, shops, workshops, homes and rural hospitals. JGS put this unease and anxiety to rest. The temptation, especially among the young, to move to towns has declined as village life has become markedly less irksome and more comfortable after JGS. The JGS has helped to bridge a major divide between rural and urban life. An improved power supply has led to better drinking water supply for longer hours, improved street lighting, use of television, radio, kitchen gadgets and fans. Women in many villages used the time saved from household chores for supplemental income generation. The JGS paved the way for the better functioning of schools, primary health centers, dairy co-ops, and better communication.

Jyotirgram Impacts on Non-farm Rural Economy

The JGS has given a big shot in the arm to existing and new non-farm economic enterprises, generating new livelihoods and jobs. The JGS has reduced the cost of non-farm businesses such as flour and rice mills, which now do the same amount of work by consuming less power because they get full-voltage, uninterrupted 3-phase power supply round the clock.[3] Many of those we interviewed reported 30-35 % fall in their bimonthly power bill, during post JGS (Talati). Many rice mills owners we met told us that they were able to increase their daily output by three times, create more local employment opportunities and enjoy a reduction in maintenance and repair costs, breakdowns and working capital requirement. Many shops, especially those vending perishable food items, telephone exchanges and Subscriber Trunk Dialing STD booths, computer training centers had to make significant investment in invertors or generators during pre-JGS. Today, inverters and gen-sets have by and large disappeared and commercial outfits are now able to operate in a continuous manner because of JGS. In Banaskantha as well as Bhavnagar villages, we found diamond polishing units shifting to villages to save on expensive rental space in towns. And, as a result, the demand for labor in this sector has increased so much as to create farm labor shortages, especially during harvest time. In some of the villages, flour mills that were running at great cost with diesel engines during pre-JGS, have now turned electric. In the Bhavnagar District, JGS stimulated growth in employment, and wage rates, in diamond polishing, tailoring, knitting, cool drinks, welding, and small oil mills. Many women, unable to commute to the urban centers of diamond polishing trade, have now begun to work in newly opened diamond cutting/polishing units in their own villages. According to a local leader, “thanks to JGS, Bhavnagar villages have witnessed more progress and better incomes during the last 3 years than in (the) 50 years before (JGS).” According to another, “JGS has good and bad things for farmers, but it has only good things for the village as a whole.” Some dairy farmers averred they produced more milk simply because buffaloes felt happier in the comfort of electric fans. In most districts, electronic and electrical repair shops experienced major improvements in efficiency and speed. Welding machine owners and tire puncture shops improved their business substantially. The demand for electronic products such as TV sets, DVD players, and tape recorders increased rapidly. Cold drinks and frozen food shops experienced 10-20 % increase in business, especially during long summer months. Tailors improved their productivity and income by up to 40 % by attaching electric motors to their sewing machines.

---

[3] Thus, non-farm units making illegal use of tota’s paid commercial rate for power on metered basis and did not extract a subsidy, which to ta-using farmers did.

However, there is one sector of the non-farm economy that was hit hard by the JGS, i.e., the motor/pump repair and service industry. Its fortunes have always been tied to poor quality power supply. During recent decades, rural Gujarat had witnessed booming ancillary trade tied to tubewell irrigation. Some of this involved drillers, rig owners, cement pipe manufacturers, gangs specializing in laying buried pipeline networks, specialists for taking submersible motors out of tubewells and for installing them inside tubewells, specialists for adding new columns to chase falling water levels. Some more had to do with the maintenance and repair of tubewell equipment, especially pumps and motors, manufacturing and installing capacitors (*totas)*. This second trade proliferated as rapidly as Gujarat's farm power supply deteriorated. But with JGS, these pump repairing units and motor-winders have fallen into bad days. According to M.S. Patel, one of our research partners, JGS has killed 3 birds with one stone: 1) it has provided succor to tubewell owners by easing the huge burden of maintenance and repair they had to shoulder all these years; 2) it has saved GEB from big losses; and 3) it has also saved groundwater tables from receding. The only non-farm trades that are adversely affected by JGS include motor rewinders, capacitor makers and pump repairers (Patel).

Jyotirgram Impacts that Tubewell Owners Laud

The farmers we interviewed welcomed five major changes that the JGS has brought about:

1. *Continuous power supply*: Before JGS, numerous tripping in farm power supply made it impossible for farmers to keep their irrigation schedules. Frequent tripping wasted water and power; motors suffered increased wear and tear; and tubewell owners, water buyers as well as hired laborers suffered forced idle time during the power outages. By providing power with greater continuity and fewer interruptions, JGS has benefited farmers.

2. *Full voltage*: Low and fluctuating voltages, in part due to the rampant use of *tota*s by farmers themselves, was another problem. This resulted in the frequent burn out of motors, and high wear and tear. Post-JGS, there was no need for capacitors due to regulated power supply, which besides improving voltage also helped to improve order and discipline in electricity use in agriculture.

3. *Reliability and predictability*: Before JGS, farmers could never know in advance precisely when power would be supplied and withdrawn. Tubewell owners and their customers were always on tenterhooks, waiting all day for power to come so they could begin irrigation. Auto switches were widely used on tubewells, which got switched on as soon as the power supply started. After the JGS, farmers get their ration of 8 hours of power during a fixed time schedule, known to everyone, during day and night in alternate weeks, making irrigation scheduling easier for tubewell owners and their customers.

4. *Externally imposed restraint*: Some farmers, though not all, grudgingly recounted that the JGS successfully attacked the common-property externality inherent in groundwater irrigation. It did this by effectively putting a cap on collective groundwater withdrawal

in a 'uniform' and 'just' manner. Farmers everywhere recognized that unbridled pumping of groundwater must eventually prove the highway to disaster. Farmers also knew that on their own they would never forge collective self-regulation. JGS has done it for them by rationing power uniformly on all tubewells across the state.

A similar sentiment was expressed about the use of capacitors (*tota*s). Many farmers felt guilty about the use of *totas*, but used them simply because everyone else did so. Post-JGS, all farmers have been forced to give up the use of totas. With the separation of tubewell and non-tubewell feeders, use of *totas* to run tubewells has become technically impossible for most farmers. Moreover, the use of totas is also vigorously monitored and heavily penalized. The sense of relief was particularly notable in hard-rock areas like Sabarkantha, where wells run out of water before pumps run out of power during a day. Before JGS, there was a frenzied urgency among *tota*-using tubewell owners here to pump as much groundwater as they could under a 'use it or lose it' regime. By abolishing *totas*, the JGS took the first big step towards a sustainable groundwater management regime that most tubewell owners welcomed.

5. *New connections*: When the JGS was completed, the Government of Gujarat lifted the virtual embargo on new tubewell connections and began offering new connections in a planned manner, depending upon the availability of groundwater and power.[4] In parts of Saurashtra, where a profusion of check dams and recharge structures have increased recharge to the hard-rock aquifers, new connections were released. This was also the case in some parts of central and south Gujarat.

Jyotirgram Impacts that Farmers Loathe

If the above paragraphs suggest that all farmers are as unreservedly happy with JGS as housewives, students, owners of non-farm trades and enterprises are, nothing could be farther from truth. In fact, the negative sentiment among farmers is stronger and more widespread than the positive feeling. Farmers viewed full-voltage, reliable power supply as nothing more than a sugarcoating on the bitter pill of rationed power supply. Particularly peeved were tubewell owners in the groundwater abundant areas of central and southern Gujarat who operated their tubewells for up to 18-20 hours daily using capacitors (*tota*s). Now they are forced to make do with just 8 hours. Vibrant water markets, which have been central to Gujarat's groundwater irrigation economy, are also essential for the viability of tubewell investments that have been in existence for eight decades (Shah 1993). Howver, these are now under siege because of effective power rationing.

---

[4] Every year, the government determines how many new connections can be given out in the entire state depending on the groundwater level and power available. Allocations made to districts, circles, divisions and feeders were advertised through local newspapers inviting applications for new Tatkal connections. The connections are then given out on a first-come-first-serve basis. Such a system ensures that the GEB has a fairly strong control over new tubewells in the state.

Farmers we interviewed were bitter about promises unkept, e.g., 8 hours of continuous, full voltage, 3-phase power (ToI 2002). Farmers still face frequent trips, lower than full voltage and effective hours of daily power supply of 6 to 6.5 hours against the promised 8 hours. Night power supply every alternate week is another sore point. Night irrigation is inconvenient and hazardous, and finding labor to work in the fields at night is a trying exercise. The crucial issue, however, is effective rationing. Many farmers complained that “it is unfair on the government’s part to divert agricultural power for residential users. Agriculture is the back bone of the village economy. When agriculture itself is threatened, how can a village enjoy better life?” (Talati). In Vadodara, farmers lamented that “the government has pursued rural development at the cost of agriculture” (Modi). In Dahod, tribal farmers complained, “but for us farmers, Jyotirgram has benefited all else” (Sheikh). In Kheda, all our respondents, including women members of families, strongly felt that villages should not enjoy 24x7 power supply if it comes at the cost of agriculture. Some suggested that 24 hours single phase power should be supplied to the residential users; 3-phase power line to industries and water works should be separated; and a uniform 12 hours continuous power supply should be ensured to farm and non-farm producers (Talati).

Jyotirgram Impacts on Marginal Farmers and the Landless

The brunt of the adverse socioeconomic impact of the JGS fell on the water-buying marginal farmers, tenants and landless farm laborers. This large section of Gujarat’s agrarian poor depends upon tubewell owners to sell them reliable pump irrigation at an affordable price; and ironically, the much-despised *tota* system ultimately benefited these classes. With drastic diminution in pump irrigation sales, the agrarian poor are left in the lurch. We encountered only three situations where this did *not* happen. First, in water-stressed hard-rock areas like Bhavnagar where, owing to the limited availability of water in wells, pump irrigation markets were all but absent even before the JGS. Here, the small and marginal farmers who were rain-fed farmers before the JGS continue to be so even after JGS without any further worsening of their position (Oza). Second, in canal irrigated areas where canal irrigation, high tubewell density, high water tables and good well yields combine to make 8 hours of power sufficient for meeting the villages’ irrigation demand. During post-JGS, the terms of share-cropping have remained largely unchanged, which means that landowners have absorbed the JGS shock (Bhatt). Third, in the prosperous and groundwater-rich South Gujarat, where most farmers had their own electrified bore-wells and water markets were limited. Post-JGS, what little pump irrigation trade that existed shrank even further, and we found there was no major increase in the water price (Soni).

Almost everywhere else, our researchers found that marginal farmers and landless laborers were hit hard in several different ways, e.g., (a) groundwater markets shrank, and irrigation access to buyers declined; (b) pump irrigation prices in cash sales post-JGS increased 40-60 % or more everywhere;(c) landless laborers cultivating leased land faced reduced availability of irrigation; (d) they also faced reduced opportunities for farm work as the total irrigated area declined (Padkaar 2007). Often the bottom of the agrarian pyramid comprises migrant tribal laborers, the *Harijans* and low castes that are often the least skilled and adapted to non-farm trades where JGS has opened up new vistas for growth and prosperity.

Assessment

Evaluations of JGS so far have focused mostly on the non-farm economy and the quality of domestic life – where JGS impacts are unambiguously salutary. Our study has a larger ambit in that it covers JGS's impact on the political economy of groundwater irrigation in Gujarat, and as a result, it also points at some negative impacts that need addressing. In summary, our assessment of the impacts of JGS on different stakeholder groups is summarized in Table 1.

Table 1. Impacts of the 'Jyotirgram' scheme on different stakeholder groups.

Stakeholder group	Positive (+)/Negative (-)
Rural housewives, domestic users	+++++
Students, teachers, patients, doctors	+++++
Non-farm trades, shops, cottage industries, rice mills, dairy co-ops, banks, co-operatives	+++++
Pump repair, motor rewinding, tubewell deepening, etc.	- - - - -
Tubewell owners: quality and reliability of power supply	+++
Tubewell owners: No. of hours of power supply	- - -
Water buyers, landless laborers, tenants	- - - - -
Groundwater irrigated area	- - -

Source: Authors' assessment based on case studies

In tribal districts like Dangs and Dahod, where the groundwater economy is small and primitive, JGS's impacts can be seen in the improvement of quality of rural life as well as in the non-farm sector. However, its agrarian impacts are subdued. Here, groundwater use in agriculture is small; exchange of pump irrigation service is often a kinship-based transaction; and 8 hours, if provided, is too much power supply for most wells, which in any case operate often with diesel pumps. People's perception of JGS is entirely positive here, because they see its beneficial impact on shop keepers, artisans, local employment, public health centers, schools (Sheikh). However, the agrarian dynamic of JGS comes to the fore only in areas where agriculture and rural livelihoods have come to depend critically on the working of groundwater markets.

Political Master-stroke

JGS offers a case study of astute political management by intervening in an arena surcharged with animated mass politics. International lenders and power sector professionals have been surprisingly naive in coming to grips with the politics of metering tubewells. A study of farmer attitudes towards tubewell metering by Joshi and Acharya (2005) in North Gujarat showed the overpowering sense of antagonism and suspicion that farmers displayed on the issue. Over the past decade, mass-based resistance to metering has stopped the moves by several other states in this direction. Yet, the ADB made universal metering a condition in its power sector reform loan to Gujarat. And in 2002, ADB withheld the release of funds when Gujarat failed to make progress on metering tubewells. "It was not released as the conditionalities of coming up with the Electricity Reforms Bill—empowering the Gujarat Electricity Board for cent per cent metering of the farm sector and corporatising its generation, transmission and distribution networks was not passed in the state assembly." (ToI 2002).

The IWMI second-best strategy—designed to minimize farmer resistance—too would have invited some resistance. However, Gujarat government's strategy of projecting JGS as an intervention to "to provide continuous 3-phase power supply to the rural area for upliftment of rural population" (EPD 2007), was a political master stroke to create a powerful rural support base to counter tubewell owners' resistance to power rationing. "The central purpose of this project is to remove disparities between urban and rural areas in the power supply and in other services available to the people" (MGVCL 2007). Before JGS, farmers, their families and most others viewed farmers as victims of a reformist government that is insensitive to their plight. The JGS, however, won supporters even within farm families, and even among some farmers. The JGS was not imposed, but it was actually marketed to village communities. For example, a village panchayat had to pay a registration fee of Rs 1,000 and 30 % of the cost of rewiring. It was first launched in the poorest districts such as Dangs, where its impact was bound to dazzle. It was also implemented early on in prosperous districts like Anand with its high water tables. Here, non-farmers placed a high value on improved power supply environment, and farmers were less worried about power rationing. Last to be covered were North Gujarat and the Saurashtra districts, where farmers would be hit hard by power rationing. Village contribution was waived in all these 'problem' districts that have high groundwater dependence and low water levels.

The JGS could do this because it realized that for decades, rural life i.e., homes, shops, schools, public health centers, had become hostage to the groundwater irrigation economy. By far the majority could not realize that they had to suffer power cuts, low voltages, frequent outages and trippings largely because of tubewell irrigation. By separating tubewells from the rest of the village, the JGS liberated the village life and economy from the shackles of the political economy of power subsidies for tubewells.

Jyotirgrams and the Energy-irrigation Nexus

Against its original objectives of improving the rural power scenario and the viability of the. Gujarat Electricity Board (GEB), the JGS has proved to be an outstanding intervention. During the past 5 years, Gujarat has emerged as one of the best performing states in the management of its power sector. The GEB, with its annual losses falling from Rs. 2,200 crores in 1999-2000 to Rs 475 crores in 2002-03 and perhaps even more since then,[5] is turning around. Farm power tariff, which stagnated at Rs. 350HP/year and Rs. 500/HP/year for pumps less and more than 7 HP, respectively, have been raised to Rs. 800/HP/year.[6] Agricultural power subsidies were a

---

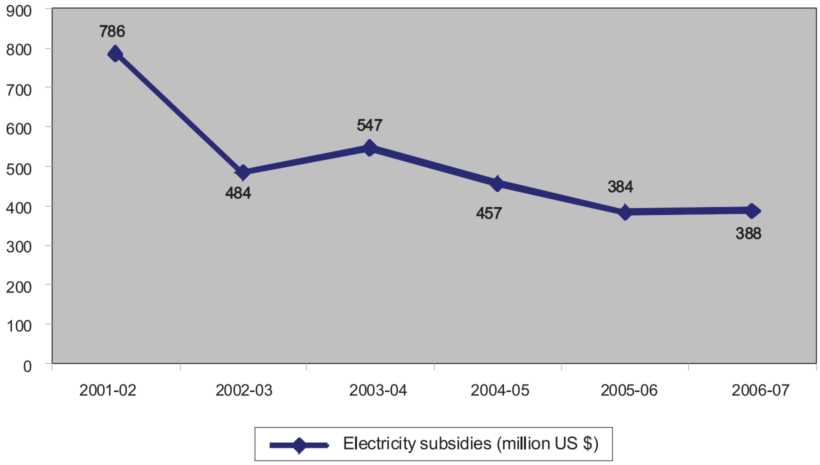
[5] MGVCL (Madya Gujarat Vij Company Ltd.), the new 'corporatized' version of GEB in central Gujarat, has made operating profits in 2005-06, for the first time in several years.

[6] This has not been easy with strong farmer organizations resisting all moves to rationalize the tariff. In 2002, Chief Minister Modi tried to raise this from Rs. 350-500 to Rs. 1260/HP/Yr and the move was immediately opposed by the Bhartiya Kisan Sangh (BKS). After sustained agitations, the rate was fixed at Rs. 850/HP/Yr. For metered connections, the tariff remains Rs. 0.50/kWh; and for Tatkal connections, it is Rs. 0.70/unit.

millstone around the neck of Gujarat's electricity industry, and it is still an issue, but JGS has created a wherewithal to 'manage' farm power subsidies within acceptable limits. As the IWMI proposal had pointed out, the problem with pre-JGS power tariff policy was not only that it led to large power subsidies; the problem was also that the government had no control over the volume of subsidy extracted by *tota*-using tubewell owners. With effective power rationing in place, JGS has transformed a degenerate flat tariff into a rational flat tariff, with the government having firm control on the total volume of farm power subsidy.

Since over 90 % of groundwater withdrawal in Gujarat occurs through electrified tubewells, electricity consumption is an accurate surrogate of the aggregate groundwater withdrawal. Government figures suggest that farm power use on tubewells has fallen from over 15.7 billion units/year in 2001 to 9.9 billion units in 2006, a nearly 37 % decline. This has resulted in halving the aggregate farm power subsidy, from US$788 million in 2001-02 to US$388 million in 2006-07 (Figure 2), and also causing a considerable decline in the aggregate groundwater draft. Although some of the decline may be caused by the two successive good monsoons in 2005 and 2006, there is unmistakable evidence of tubewell irrigation shrinking.

Figure 2. Reduction in Gujarat government's electricity subsidies (million US$).

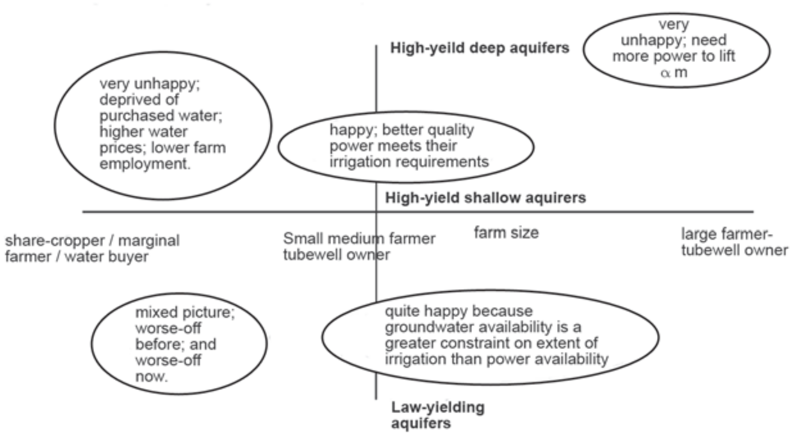


Source: Patel, 2007

Agrarian Impacts

Dazzled by what 24x7 3-phase power supply can do to village life and non-farm economy, many lay observers and even researchers like IRMA and CEPT have glossed over the agrarian distress JGS has been causing. True, some of the reduction in groundwater withdrawal represents saving of waste; but a good deal more represents reduced irrigation, lost output, livelihoods and employment. The angst this is causing among the farming community is all too clear from the accounts provided by our research partners. But the depth of the angst is not uniform as suggested in Figure 3. The key determinants of farmer angst are two: a) size of the landholding and b) the nature of the aquifer. In depleted alluvial aquifers of Mehsana and Patan, farmers who can pump their deep tubewells, continuously feel adversely affected because

Figure 3. Jyotirgram's impacts on diverse sections of Gujarat's farming community.



the power ration restricts their area irrigated. But farmers in hard-rock areas are less affected because water available in their well during a day is a more binding constraint on their pumping than the hours of daily power supply. Small farmers owning tubewells are happy with improved power quality although they miss their water selling business. Landless share croppers and water buyers are adversely affected everywhere, as water markets have shrunk and water prices have soared 40-60 %, driving many of them out of irrigated agriculture. The full import of rationed power supply has yet not been felt by farmers, because 2005 and 2006 were both good monsoon years when wells were full and water levels close to the ground. Come a drought year, and farmers will find the JGS ration of power too meager to meet their irrigation needs.

It is very likely that Gujarat's agriculture is still in the transitory phase of adjusting to post-JGS groundwater irrigation regime. Our hypothesis is that post-JGS, farmers will increasingly turn to water saving crops and irrigation technologies, experience renewed interest in gravity-flow irrigation and give a new impetus to water harvesting and groundwater recharge work that can improve their well's yield. The Government of Gujarat is already doing a good deal to support movement in this direction; but more can and needs to be done, if anything, to limit farmer distress arising from rationed farm power supply. A great deal of farmer frustration arises from promises un-kept. For example, JGS promised farmers 8 hours of continuous, full voltage daily power supply. These un-kept promises can be addressed by better housekeeping and tighter operational management. Pre-JGS, the Electricity Board had some justification perhaps in 'not' treating the farm user as a customer because he paid a subsidized rate; but under JGS, real farm power subsidies are a fraction of what they were pre-JGS. Hence, it is time electricity companies began treating the farmer as a customer deserving quality service.

Who Benefited from Farm Power Subsidies?

It has always been a matter of intense debate in Indian literature on precisely who the beneficiaries are of electricity subsidies under a flat tariff regime. Most analysts have argued that farm power subsidies essentially benefit the large farmers who own most electric tubewells.

The analysis offered by Howes and Murgai (2003) for Karnataka was a classic statement of the perverse nature of the electricity subsidy under the flat tariff regime, which distorted power economics, depleted groundwater and enriched the rural rich.

All the evidence we collected suggests that the brunt of rationed power supply under JGS has fallen not on tubewell owners but on marginal farmers and landless laborers. To ascertain this position better, our research partners went back to their respondents for a second round of enquiry (Table 2). This confirmed that post-JGS, the groundwater irrigation through water markets has seriously shrunk in many districts, hitting the water buyers hard. In response to rationed power supply and the abolition of the use of the *tota*, tubewell owners have made good their losses from the reduced volume of pump irrigation sales by increasing pump irrigation prices from 30-60 %, reducing the cost of wear and tear and enhancing bargaining power to make favorable deals with marginal farmers and share croppers. It is the latter who have lost from the abolition of the *tota* system and from the shrunken pump irrigation markets. This is evident from the reduced opportunities for irrigated share cropping, and in marginal farmers being eased out of the pump irrigation economy. The JGS experience shows that controlling electricity subsidies and groundwater overdraft do not come without a significant social cost in the form of causing more misery to the agrarian poor who are miserable in the first place.

Table 2. Responses from eight research partners on the second round of questions.

Researcher		District and number of farmers consulted	Has the area irrigated by tubewells declined after JGS?	Are metered tubewell owners more or less keen to sell water compared to flat rate tubewells?	Do metered tubewell owners charge a higher water price compared to flat rate tubewells?
1.	R.K.Shah	Patan (8)	Yes, to some extent	Significantly less	No clear data
2.	Paresh Rawal	Banaskantha (9)	No clear picture[a]	No clear data	Yes, 50 % higher
3.	Nila Oza	Bhavnagar (8)	No decline[b]	No water markets	Not applicable
4.	Jayesh Talati	Kheda (7)	25-40 % decline	Yes. Much less keen	Yes, 30-40 % higher
5.	Tushar Hathi	Anand (36)	Significant decline in tobacco irrigation	No data	No clear data
6.	R.C. Popat	Rajkot (8)	15-20 % decline	Metered tubewells stopped selling	Not applicable
7.	Sonal Bhatt	Anand (10)	No decline[c]	No difference	No difference
8.	M.S. Patel	Sabarkantha (25)	No decline[d]	Much less keen	Yes, 30-35 % higher
9.	M.G. Sheikh	Jhalod([5)	No decline	No major difference	No difference
10.	Rama Shah	Sabarkantha (8)	Significant decline	Much less keen	Yes, 40-60 % higher

Source: Based on the 10 case studies

Notes: [a] Because last 2 years had good monsoons

[b] In hard-rock areas of Bhavnagar, water availability in wells was a more binding constraint on area irrigated than electricity availability. Power rationing thus had no impact on irrigated area

[c] But there is evidence of lengthening of irrigation interval

[d] However, water buyers often do not get water when they need it

The Government of Gujarat has made metered tariff mandatory for all new tubewells. Our studies also suggest that metering too comes with a 'welfare cost', because metered tubewell owners manifest a markedly less interest in selling water to their poor neighbors than flat tariff paying tubewell owners, even though the former pays a highly subsidized rate per kWh. In Rajkot, after the JGS, "farmers having meter-charged power have stopped selling water" (Popat). In Kheda, our researcher wrote "it is true that metered tubewell (TW) owners are less interested (in) sell(ing) their water when compared to flat tariff TWs" (Talati). In the Sundha village of Banaskantha, we found farmers with 20 hp flat tariff tubewell "sell(ing) at Rs. 40/hour while Rs. 60/hour is taken by metered tubewell owners with 20 hp pumps" (Rawal). In the Patan District, our research partner wrote: "tubewell owners under flat charge sell more to other farmers and irrigate more land, but those with meters use their tubewells only for their own irrigation and prefer not to give water to other farmers… they are always conscious that the meter is running and, therefore, refuse to irrigate others' land" (R.K. Shah). In Anand, "farmers having a flat rate electricity connection maximize their sale through reducing water rates, provided a buyer is available.."; our researcher found the water-price formation a complex affair but asserted that "generally, flat rate connections supply water at a cheaper rate than metered connections" (Bhatt). In Sabarkantha, "metered tubewell owners are less prepared to sell water, while flat rate tubewells are more eager to sell provided they have surplus power. In the Bavsar village, flat rate tubewells of 10-15 hp sell water at Rs. 25-30/hour, while metered tubewell owners charge Rs. 35-40/hour" (Patel).

In the course of our interactions, a major area of farmer concern was the growing tension between farmers and distribution company field staff. Our research partners felt that the electricity companies need to alley farmers' fear of their staff, especially now that the practice of using capacitors is nearly abolished. Before 1988, farmer resistance to metering arose in some part because of the tyranny and arbitrariness of the meter readers. Flat tariff was comforting because it minimized the contact between farmers and electricity board staff and contained the latter's arbitrariness. We found that this antipathy is returning. An area of priority action should be to establish a relationship of trust between farmers and electricity company staff. One way to do this is to rethink the purpose of metered tariff collection in a regime of stringent power rationing. When power consumption at feeder level is tightly metered and monitored, metering each tubewell offers limited scope to improve energy budgeting and accounting. However, from the viewpoint of improving irrigation access to the agrarian poor and reducing farmers' antipathy towards distribution company field staff, metering of tubewells may have serious adverse impacts. Even if tubewells are metered for energy audit purposes, if their owners are subjected to flat tariff, their behavior would change instantly. And, as a result, instead of reticent water sellers charging high monopoly premium from their poor buyers, metered tubewell owners in groundwater abundant areas would turn into aggressive water sellers expanding groundwater irrigation opportunities for the poor in their neighborhood.

The Case for the Last IWMI Recommendation

It is the alleviation of the misery of the agrarian poor that imparts new significance to the only recommendation of the IWMI proposal (Shah et al. 2003*)* that the JGS did not incorporate: the need to target maximum power supply during periods of peak irrigation demand. The IWMI proposal argued that the farmers' derived demand for power is unlike that of domestic or industrial users who need 24x7 power supply. Farmers need power mostly on 30-40 days of the year when their irrigation need peaks. A farm power regime that supplies maximum power to agriculture on those carefully selected 30-40 days and reduces daily power supply during the rest of the year to a maintenance ration of 3-4 hours would help farmers more than a uniform 8 hours/day of power supply would.

Under JGS, the government has committed itself to supplying 2,880 hours of farm power/year. There are a number of ways this same quota can be delivered to maximize its beneficial impact on the agrarian poor and on agriculture as a whole. In order to surface farmers' preferred season-adjusted power supply schedules, in our second round of enquiry, we asked our respondents to allocate an annual ration of 3,000 hours of farm power (@ 8.30 hours/day) over the 12 months. The responses we received (see figure 4) showed considerable variations across districts. However, everywhere, farmers allocated more hours of farm power to November-March months than the rest of the year. Aggregating the preferred schedules provided by all the respondents suggested two distinct patterns, which are displayed in figure 5: (a) in a year of normal or good monsoon, farmers would like power-hours reduced during kharif and increased to 11-12 hours/day during the rabi season and 8-9 hours/day during summer; (b) during a drought year, however, farmers would like 12-14 hours/day during kharif, 10-11 hours/day during rabi and a smaller ration of 5-6 hours/day during the summer months.

Another way a power supply regime can be fine-tuned to create value for farmers is to adjust it to regional hydrogeological specifics. . True, matching rationed power supply to each individual farmer's need is impossible; but it is possible to make adjustments according to broad regional parameters. In hard-rock areas, where wells run out of water after a few hours of pumping, it would help farmers a great deal to provide their power rations in two daily shifts, as is already being done in some parts of Sabarkantha.

Figure 4. Farmers' preferred distribution of 3,000 hours of electricity: 150 tubewell owners sampled in eight districts of Gujarat.

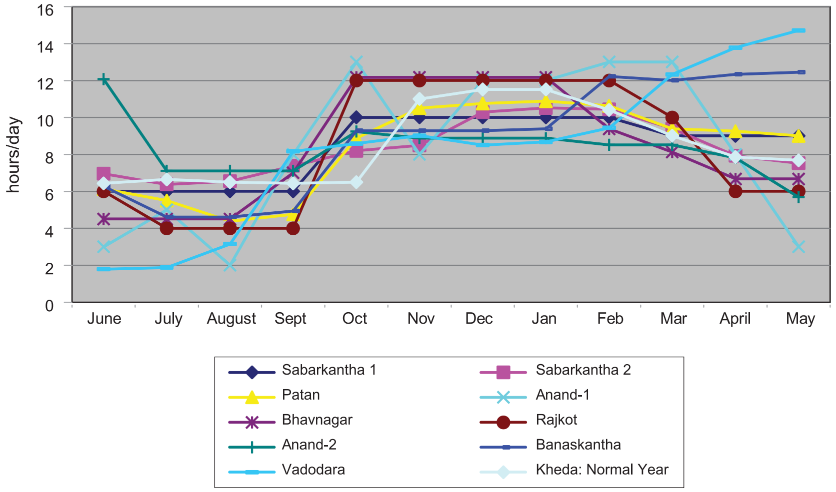
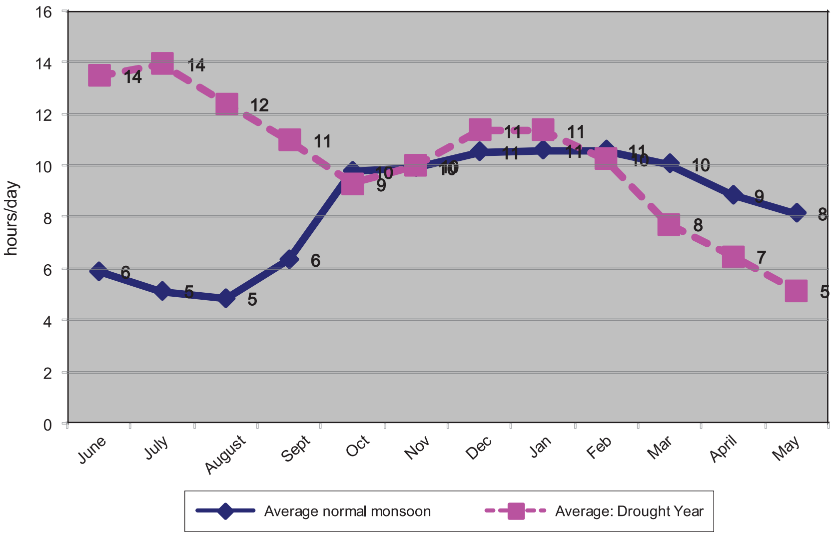


Figure 5. Aggregated preference of farmers about daily power supply during different months.



The Grand Promise of Jyotirgram

In our assessment, JGS has pioneered the real-time co-management of electricity and groundwater irrigation. It has unshackled domestic and non-farm rural electricity supply from the clutches of an invidious political economy of farm power subsidies. Its highly beneficial and liberating impacts on rural women, school children, village institutions and the quality of rural life are all too evident; its impact on spurring the non-farm rural economy are incipient but all indicators suggest that this will be significant and deepen over time. Post JGS, Gujarat is well on its way to putting its electricity industry on a sound footing in just over 5 years. Gujarat now has a kind of switch-on/off groundwater irrigation economy in which the administration has a powerful handle for groundwater demand management, which is another benefit of JGS. Elsewhere, governments have tried, mostly in vain, to manage groundwater by making laws that are unenforceable, or by vague notions like tradable groundwater rights. In comparison, Gujarat under JGS has shown that the effective rationing of power supply can indeed act as an all powerful tool for groundwater demand management. It can be used to reduce groundwater draft in resource-stressed areas and to stimulate it in water-abundant or waterlogged areas; it can be used to stimulate the conjunctive use of ground and surface water; it can be used to reward ‘feeder communities’ that invest in groundwater recharge and penalize villages that overdraw groundwater as if there is no tomorrow. A big breakthrough is the control the government now has on the size of the farm power subsidy: pre-JGS, *tota*-using tubewell owners subject to flat-tariff availed themselves of all the power they wanted with the government and electricity board being reduced to helpless bystanders. Now, tables are turned; tubewell owners have to manage with the power they are provided. In this sense, JGS has transformed what was a highly degenerate power-pricing-cum-supply regime into a rational one.

The JGS, however, has a big downside too, the brunt of which is borne largely by marginal farmers, and the landless, because of the shrinking of water markets and of groundwater irrigation itself. There is no way of eliminating this completely except by increasing hours of power supply – and subsidy – that tubewell owners everywhere are crying for. However, JGS can significantly reduce the misery of the agrarian poor by adjusting the schedule of power supply to match peak irrigation periods, especially for the rabi season. Providing the daily power supply in two or more installments to respond to the behavior of wells in hard-rock areas can further help the poor. Charging a common flat tariff to all tubewells regardless of whether metered or not can also stimulate metered tubewell owners to share irrigation with the poor.

The JGS has lessons of enormous significance for eastern Indian states - that, under the degenerate flat tariff regime, rural electrification is held hostage to farm power subsidy is nowhere more evident than in eastern India, where the country-side has got all but ‘de-electrified’ (Shah 2001), holding up rural development in that entire region. Orissa has tried to reverse this retrogression by metering tubewells; and West Bengal too is preparing to take that route, but this runs the risk of throwing the baby with the bathwater. Gujarat’s JGS experience offers an important alternate model, which we consider is superior in many respects.

References

Bhatt, Sonal - case study of Anand villages.

EPD. 2007. *Jyotigram Yojana.* Website of the Energy and Petrochemicals Department, Government of Gujarat. [http://guj-epd.gswan.gov.in/epd_jyotiyojna.htm]

Hemchandracharya North Gujarat University and CEPT. 2004. “Powering Rural Gujarat: A Rapid Impact Assessment Study, Districts: Mehsana and Patan,” Ahmedabad: Centre for Environmental Planning and Technology.

Howes, S.; Murgai, R. 2003. Incidence of Agricultural Power Subsidies: An Estimate. *Economic and Political Weekly*, April 19, 2003. Also see, Narendranath, G., Umashankari and Reddy, K.R.. 2005. To Free or Not to Free Power: Understanding the Context of Free Power to Agriculture. *Economic and Political Weekly,* December 31, 2005.

IRMA. Nd. “Impact Assessment of Jyotirgram Yojana in Gujarat” report of a study for the Confederation of Indian Industry by Institute of Rural Management, Anand.

Joshi, V.; Acharya, A. 2005. *Addressing agricultural power subsidy: A case study of north Gujarat.* Working Paper 2. Surat, India: Center for Social Studies.

MGVCL. 2007. *Jyoti Gram Yojana - Lighting Up Life*. Website of the *Madhya Gujarat* Vij Company Ltd. [http://www.mgvcl.com/page2.htm].

Modi, Rajesh - case study of Vadodara villages.

Naya Padkaar - Friday, 12 January, 2007 an example of these impacts in Dharmaj village of central Gujarat where tubewell owners raised water prices from Rs 20/hour to Rs 50 post-JGS

Oza, Nila - case study of Bhavnagar villages.

Patel, MS - case study of Sabarkantha villages.

Popat, RC - case study of Rajkot villages

PRAYAS. 2004. *Know Your Power: A Citizens’ Primer on the Electricity Sector,* Prayas Energy Group, Pune.

Rawal, Paresh - case study of Banaskantha.

Shah, R.K. - case study of Patan villages.

Shah, T. 2001. *Wells and welfare in Ganga basin: Public policy and private initiative in eastern Uttar Pradesh, India.* Research Report No. 54. Colombo, Sri Lanka: International water Management institute (IWMI).

Shah, T.; Scott, C.; Kishore, A.; Sharma, A. 2003. Energy-Irrigation nexus in South Asia: Improving groundwater conservation and power sector viability. Research Report 70. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Shah, T. 1993. *Groundwater Markets and Irrigation Development: Political Economy and Practical Policy*. Bombay: Oxford University Press. See, also, Hardiman, David. 1998. “Well Irrigation in Gujarat: Systems of Use, Hierarchies of Control.” *Economic and Political Weekly,* June 20, 1998. pp: 1533-1544.

Sheikh, MG - case studies of Dahod villages.

Soni, Jayashree I - case study of Navsari villages.

Talati, Jayesh - case study of Kheda villages.

ToI. 2002. ADB Loan to Gujarat in doubt. *Times News Network,* August 7, 2002.. [http://timesofindia.indiatimes.com/articleshow/18397858.cms]

International Experiences of Water Tranfers: Relevance to India

Francis Gichuki and Peter G. McCornick
International Water Management Institute, Colombo, Sri Lanka

Introduction

Water transfer has and continues to be a complementary water management strategy for promoting socioeconomic development in water-scarce regions. Over 2,500 years ago, the Babylonians, the Roman Empire and the Chinese constructed extensive canal networks, famous aqueducts and the Grand Canal, respectively to support human settlement in water- scarce areas. The Anuradhapura Kingdom of Sri Lanka too, developed major water transfers as far back as 100 AD to support the irrigation civilization needed to feed a growing population (de Silva 2005). In the twentieth century, the phenomenal population growth, economic activities and human settlement in water-scarce regions, advances in science and technology, political will and availability of resources led to the development of many water transfer projects. The global inter-basin water transfer increased from 22 to 56, from 56 to 257 and from 257 to 364 $km^3 yr^{-1}$ during the periods 1900-1940, 1940-1980 and 1980-1986, respectively, and is estimated to increase to 760-1,240 $km^3 yr^{-1}$ by 2020 (Shiklomanov 1999). Most of these transfers took place in Canada, the former USSR, India and the United States of America.

The benefits of these transfers have been considerable. Well-implemented water transfer schemes have supported socioeconomic development by: (a) enhancing total water benefit through the transfer of surplus water to a water-scarce basin/region; (b) facilitating re-allocation of water from a low- to a high-value use; (c) reducing regional inequity by transferring water to promote socioeconomic development in water-scarce regions; (d) facilitating broader cooperation and promoting solidarity between donor and recipient regions; and (e) restoring degraded freshwater ecosystems. However, the poor social, financial, economic and environmental performance of some transfers has contributed to growing criticism. Over the last 2 decades, most of the planned transfers have stalled. Yet, the Comprehensive Assessment of Water Management in Agriculture (CA 2007) concluded that, while improved water management should offset the need for securing new water sources, it cannot do this in all cases. It postulates that calls for water transfers will likely increase and become louder when and where the mismatch between supply and demand continues to grow, and efforts to conserve water have been exhausted. Tumbare (2001) argued that while the proposed inter-basin water transfer schemes in southern Africa seem to be pipe-dreams, they will become a reality in the near future due to continued population and economic growth in the region, and as long as there is scope for a win-win negotiated outcome. He postulated that these schemes will bring closer ties, economic benefits and co-operation between the various countries. Hence the need to address the question: how can future water transfer schemes be planned, implemented and operated cost-effectively and in ways that maximize net benefits and minimize social and environmental costs?

We posit that there are valuable lessons, both positive and negative, to be learned from past experiences, and also acknowledge the fact that the future is likely to present new challenges and opportunities and, hence the need to take a cautious approach. We, therefore, contribute to answering the above question by reviewing global experiences of water transfer and drawing lessons on where, when and how to implement economically, socially, environmentally and politically acceptable water transfer schemes. We specifically address the following questions:

- What are the different types of water transfer systems and under what conditions are they appropriate?
- What are the effects of water transfers on agriculture, food security and poverty?
- What factors facilitate or constrain the effective implementation of water transfer schemes?
- What changes in policy, legal and organizational framework and in approach to project design, planning, implementation and operation are required to facilitate the development of judicious water transfers schemes?
- How can research contribute in informing the debate and in providing solutions to unforeseen problems?

Types of Water Transfers and Case Studies

Types of Water Transfers

Water transfer is a water management strategy aimed at reducing the mismatch between water supply and demand by transferring water to augment local supply in water-scarce areas or reduce damage caused by excess water. Water transfer has three dimensions. First, water can be transferred from one use/user (donor) to another (recipient). Common examples include the transfer of water from agricultural to urban use and the transfer of water rights from one user to another, either through water trading, at the expiry of the water right duration, or where one user simply takes the water with no compensation to the previous user. Second, the temporal dimension in which alternative forms of water storage (groundwater recharge, natural or man-made reservoir) increase water availability in the dry seasons by storing the excess water received during the rainy seasons. Third, the spatial dimension involving the transfer of water from one location to another using groundwater pathways, natural waterways, canals and/or pipelines. These dimensions are not mutually exclusive and in most cases occur in combination.

Water transfer requires that there be a social, environmental, political or economic benefit, which provides the justification to offset: (a) the cost of transferring it; (b) any compensation demanded by the donor; and (c) any other costs associated with the negative externalities that the transfer may generate. Generally, water transfer schemes have multiple complementary objectives that include:

- To increase total water benefit by transferring surplus water to a water-scarce basin/ region,[1] as is described in the Brazil case study included in this paper;
- To facilitate re-allocation of water from a low- to a high-value use;[2]
- To reduce regional inequity by transferring water to promote socioeconomic development in water-scarce regions;[3]
- To meet treaty, agreement or other legal obligations;
- To facilitate broader cooperation and promote solidarity between donor and recipient regions;[4] and
- To restore degraded freshwater ecosystems.[5]

As stated above, there are a wide range of transfers, and a variety of terms associated with them. In this paper, we classify water transfers based on the geographic scope as follows:

- inter-project - transfer within a water project;
- intra-basin – transfer from one subbasin to another in the same basin; and

---

[1] For example, Egypt plans to promote the use of water saving technologies and transfer the water saved to irrigate 168,420 hectares of reclaimed dessert and provide opportunities for 3 million people (Tafesse 2001).

[2] For example, the experiences in China and western USA, in which large quantities of water are being transferred from agriculture to urban use, agriculture to agriculture, urban to urban and agriculture to environment. These transfers may be by the same user, among users within a water project or from one administrative/hydrologic unit to another.

[3] For example, the Rio-Sao Francisco inter-basin diversions whose objectives are to meet rural water requirements, promote urban and industrial growth and stimulate irrigation development in the drought-prone parts of Sao Francisco Basin, Brazil (Kemper et al. 2002).

[4] For example, planned diversions by Egypt’s el-Salam (peace) canal to Israel and Palestine (Dinar and Wolf 1997) and by Turkey (peace pipeline project) to transfer water to Syria, Jordan, Saudi Arabia and other Arabian Gulf states (Rende 2004).

[5] By addressing environmental constraints through the use of transferred water to meet environmental flow requirements; reduce over-use of surface water, groundwater and water in wetlands and thereby sustain freshwater dependent ecosystems; and improve water quality by trading low-quality water for higher quality water and reducing agricultural pollution by transferring water to other non-polluting uses.

- inter-basin[6] - transfer from one basin to another basin. This is further sub-divided into short and long inter-basin transfers. In the case of the former, the transfer is to a basin immediately adjacent to the donor basin, whereas with the latter, it may cross multiple basins.

Other defining characteristics of a water transfer arrangement include:

- *Types of water:* the transfer may involve surface, ground, wastewater (reclaimed, treated, or untreated), brackish and even saline water. For the sake of completeness, it could also include virtual water, that is through trade.
- *Water transfer route:* can be direct (above or below ground pipelines, open or closed canals, and natural waterways) or in-direct[7] as in the case of groundwater flow.
- *Water transfer duration:* these include permanent, long-term and short-term transfers of a water right.
- *Water transfer operation criteria:* that defines the volume, rate and timing (seasonal, constant, pulsed or combination) of the water to be transferred.
- *Planned or unplanned water transfer:* While the focus of this paper is on planned transfers, it is important to recognize that there are also unplanned transfers.

Given the above, there is considerable variation on the form of a given transfer, and generalizations of their appropriateness and/or impacts may be misleading. However, matching water transfer purpose, type and characteristics with the unique site conditions is an important step towards reducing negative impacts.

Case Studies

Water Transfers in the Western United States

Using the Colorado Basin case study, we now illustrate how the western states have put in to practice water transfers.

Sharing Water and Mitigating Negative Impacts: The waters of the Colorado River are shared by Mexico and seven states of the United States of America. The Colorado River Compact of 1922 divided the water among the Upper (Colorado, Utah and Wyoming) and Lower (New Mexico, Arizona, Nevada and California) basin states and also among agricultural and urban uses.

---

[6] Inter-basin transfers is the withdrawal of water, more or less continuously over all or part of the year, by ditch, canal, tunnel or pipeline from its basin of origin for use in another river basin (ICID 2006). Further specifications include (Davies et al. 1992): (a) the diverted flow does not return to the stream of origin, or to the permanent stream within 20 km of the point of withdrawal; and (b) the mean annual flow transferred should not be less than 0.5 m3 s-1.

[7] Land and water use and management practices that increase infiltration, groundwater recharge and augmentation of dry season river flow in downstream reaches are a form of indirect water transfer.

The Compact, whose purpose was to allocate the available 17 million acre-feet (21 billion m^3) and protect the water rights of the upper basin, allocated 7.5 million acre-feet (9.2 billion m^3) to each of the two basin areas. Mexico's water issues were addressed 22 years later in the form of the United States and Mexico treaty that guaranteed Mexico 1.5 million acre-feet (1.8 billion m^3) from the Colorado River each year. Initially, the focus was on water quantity, and the water quality issues were revisited later when Mexico threatened to request international sanction for the increased salinity level of the water it was receiving. The United States agreed to limit the salinity level to 1,000 ppm. The water salinity would have been met through reduced water transfers and irrigation return flows. In 1974, to secure that water to the lower basin states, the Federal Government authorized the construction of the Yuma Desalting Plant, a reverse osmosis facility. The plant was commissioned in 1992 and tested at 1/3 capacity until late 1993 when the plant was mothballed as wetter conditions upstream meant that the required salinity levels did not require the plant's operation. Since then, the agricultural drainage water that was intended as the source water for the plant has been discharged to what was to become the Cienega de Santa Clara wetlands in Mexico, and efforts to bring the plant into operation have been resisted on environmental grounds. The recent droughts in the western United States, and the increasing demands of a growing population have increased demand on the waters of the Colorado River, while at the same time there has been increasing awareness of the need to ensure allocations to the environment. Given this, early in 2007 the United State Bureau of Reclamation (USBR) in coordination with a number of stakeholders, including the concerned environmentalists, restarted the plant for a 90-day trial period to, among other things, determine the likely impact on the wetlands.

The lessons that emerge from this section of the case study are that : (a) a government can facilitate fair sharing of water among the partner states; (b) there is need to consider third party interests and implement corrective measures associated with the cumulative negative externalities of water transfers; (c) technological solutions exist but may be too expensive; (d) in a transboundary context a poor downstream country is at the mercy of the rich and powerful upstream country and that international sanctions can play a role in getting the upstream countries to reduce negative impacts on downstream countries; and (e) the future can be very unpredictable as evidenced by changes in the hydrologic regime that in turn resulted in an under-utilization of the desalting plant and a considerable saving in operation costs, and then led to the subsequent requirement to account for the wetlands, which were created as a result of the desalination plant.

Water Transfers from Low- to High-value Uses: The western United States of America has a very rich and well-documented experience in water transfers. Early water developments and transfers were mainly for agricultural purposes. However, as the West grew, urban areas sought a share of the water. In many basins, twentieth century agricultural and urban expansion has eliminated water surplus, most notably in the Colorado-case described above. Because the water resources were initially developed principally for agriculture, agriculture obtained preferential water rights for over 90 % of the available water. In the last 3 decades, water transfer has become a common feature of water management. For example, in all western states permanent long-term lease (up to 35 years) and short-term lease (1 year) are common. Libecap (2005) reported that between 1987 and 2004 the 12 western states made 2,751 transfers. Short-term, long-term and permanent transfers accounted for 25.7 % and 68 %, while agriculture to urban, agriculture to environment and agriculture to agriculture accounted for 55%. 6 % and

16 %, respectively. In volumetric terms, the transfers from agriculture to urban, agriculture to environment and agriculture to agriculture amounted to 3.4, 3.3 and 6.8 million acre-feet (4.2, 4.1 and 8.4 billion m^3), respectively. A further 11.6 million (14.3 billion m^3) is classified as miscellaneous (urban to agriculture, urban to urban, urban to environment, environment to urban and environment to environment). These water transfers are driven mainly by market correction of water allocation failures. Griffin and Boadu (1992) illustrated this by highlighting the differences in what new water users were paying to acquire additional water—300-2,300 and 6,500-21,000 US$/acre-foot (243.3 to1,865.3 and 5,271.6 to 17,031.6 US$/1,000 m^3) in the Grande Valley of Texas for agricultural and urban uses, respectively (Trans-Texas Water Program 1998). The difference between use value in agriculture and urban indicated the significant social gain from re-allocating water from agriculture to urban. Libecap (2005) reported that the annual mean per acre-foot prices for agriculture to urban, agriculture to agriculture and other water trades were US$ 615,152 and 283, respectively. They also reported that the price differences between agriculture to urban and agriculture to agriculture has rose from US$111 in 1993 to US$1,362 in 2003.

According to Lund and Israel (1995), a series of institutional changes have facilitated the evolution of innovative water transfer arrangements. They report that the period from 1980-2000 was marked with many changes that started with the amendments of state and county laws to ensure that third parties, i.e., water users who are not a party to the transfer and fish and wildlife, are shielded from the negative impacts of the transfer. Water market and water banking are two institutional mechanisms that facilitated the efficient re-allocation of water resources. The four main types of water markets are: (a) open water market in which water rights are traded on a free market with no administrative control and interference; (b) spot markets which facilitate temporary transfers of water in times of shortages; (c) administrative water trading in which the water trade is regulated to exert some control over the spatial, sectoral, price and equity consideration; and (d) informal water markets. A water bank is an institution that offers to buy and sell water. It serves as an intermediary in the water market that encourages market activities, potentially lowers transaction costs and presents opportunities for regulating undesirable social and environmental impacts. Water markets and water banks require strong oversight to ensure that there is good governance, accountability and public trust. They also require clearly defined and secure water rights and strong water resource management organizations that can monitor the use and enforce the water rights systems.

The Colorado Big Thompson (C-BT) water project of the Northern Colorado Water Conservation District (NCWCD) is a good example of how water transfers are managed in the United States of America. The C-BT project has an extensive water storage and conveyance network that delivers water to 29 cities and towns and 607,000 hectares of irrigated land. Water is computer-controlled and an effective communication system provides real or near-real time information to water users and system managers.

The C-BT project and its water resources are owned by the US Government. The NCWCD is granted the perpetual right to use all the water available for recreational, irrigation and urban uses, and is therefore, the repayment entity, the operator of facilities and distributor of the water. These operations are overseen by the Board of Directors who have the power to make and enforce reasonable rules and regulations for the management, control and delivery of water. Irrigated land owners served by the project pay an annual levy on acreage under irrigation.

This money is used for the repayment (to the government) of the fixed cost of providing the infrastructure and for management, operation and maintenance.

Transfers of water are subject to approval by the NCWCD Board of Directors. Irrigation to urban transfers is routinely approved after examination of the need by the new user, for additional water. The transfer from one tract of irrigated land to another can be approved upon determination that the recipient land has an existing base of supply of water and that supplemental water is needed. Transfer of ownership takes 2 to 3 months after NCWCD has received and recorded all transactions. There are also brokers who facilitate water transfers at a fee. To enhance transparency, regional newspapers carry information on sale and lease opportunities (Nieuwoudt 2000). Non-profit organizations, mutual ditch companies owned by the farmers, manage delivery of water from the NCWCD operated infrastructure to the farmers' intakes. They facilitate market transactions by performing monitoring, distribution and enforcement functions. Ditch companies serve as intermediaries between the NCWCD and the irrigators. Water lease within a ditch company can be arranged by phone. Ditch companies compile their water orders and forward them to dispatch offices operated by the NCWCD, which receive and process daily orders.

The main lessons learnt from this section include: (a) administrative approaches to water allocation are gradually being replaced by market approaches that facilitate the transfer of water from low- to high-value uses; (b) administrative water trading and water banks may be required to facilitate the achievement of spatial, sectoral, price and equity objectives of water transfers; (c) effective water and communication infrastructure reduce the cost of water transfer and improve transparency, thereby enhancing public trust and confidence in the system; and (d) innovative financing arrangement comprising government financed infrastructural development, a water fee to facilitate government recovery of its finance, a cost sharing system in which by having water users and water distribution companies partially finance the infrastructural costs, public investment in water transfers can become more financially acceptable.

The Aral Sea Basin Case Study

The Aral Sea basin was formerly part of the USSR but is now made up of the five Central Asia Republics namely, Kazakhstan, Kyrgyzstan, Tadjikistan, Turkmenistan and Uzbekistan. The two main rivers Amu Darya and Sry Darya rise from the mountainous countries (Tajikistan and Kyrgyzstan) and flow northwestwardly through the arid plains and desert areas of Turkmenistan and Uzbekistan (Amu Darya River) and of Kazakhstan (Syr Darya River) and eventually flow into the Aral Sea. During the Soviet Era, 39 major reservoirs were constructed to regulate flows, generate hydropower and facilitate irrigation diversions.

The High Cost of Ignoring Negative Externalities:

Water transfers in the Aral Sea basin were mainly driven by the potential economic gains from hydropower and irrigated agriculture. During the period 1960 to 1987, the irrigated area rose from 4.5 to 8.0 million hectares and the annual irrigation diversion increased from 60 to 105 km^3 leaving less than 10 % of the natural runoff to flow into the Aral Sea (McKinney 2003). Consequently, the Aral Sea's water level dropped by 13 m and the surface area and volume decreased by 60 % and 70 %, respectively (Micklin 1988). Reduced water inflow, surface area and volume resulted in desiccation of 40 % of the wetland area, disappearance of 24 native fish species, collapse of the fishing industry and the loss of livelihoods for millions of people. Inadequate drainage in the irrigation schemes contributed to waterlogging and salinization problems in approximately 5 million hectares of irrigated land.

From this section of the case study we note that the environmental disaster, which followed from the original large-scale intra-basin transfer (from the environment to agriculture and hydropower) was enormous, and while the benefits of the irrigated cotton and wheat, and the hydropower were also significant, these negative impacts have been at an unprecedented scale. Inter-basin water transfers did not yield a high total basin wide benefit, but rather an increase in one part at the expense of another. The situation is further compounded by the fact that, unlike in the Colorado Basin case study where sufficient resources were deployed to implement mitigation measures, these cash strapped economies could not mitigate the problems. Hence, the need to critically assess environmental flow requirements and to secure these flows, particularly where many people depend on the livelihoods from such ecosystems.

From Imposed to Negotiated Cooperation of Riparian States:

Under the ‘Soviet Era’, water allocations and transfers were planned centrally resulting in some form of imposed cooperation among the riparian states. The three key features of this cooperation were: (a) water allocation among the five states—the mountainous republics (Tajikistan and Kyrgyzstan) could only utilize 25 % of surface and groundwater originating in its territory and had to pass on 75 % of the resource downstream; (b) oil producing downstream republics provided upstream republics with free oil to produce energy for winter heating so that they could secure summer flows to sustain irrigation development; and (c) upstream reservoirs were operated in a way that optimized downstream irrigation during the summer growing season rather than hydropower during the winter, and provided storage for drought security. The high potential for irrigating cotton production was the major justification for water transfers and economic cooperation (IWMI 2006).

After the break up of the USSR, new independent republics were created. With no binding interstate legal framework, some of the cooperative arrangements came under pressure as each newly independent country sought to meet their national level needs. Competition for irrigation water between the arid regions of Uzbekistan and Turkmenistan intensified, and Kyrgyzstan changed its water reservoir operating policy. It released 61-67 % higher flows in winter and 68 –77 % less in the summer from the Tokhtogul Reservoir than it did during the Soviet era (IWMI 2006). While the increase in winter flows mean the water can no longer be used in irrigation, the formation of an ice jam in the middle reaches of the Syr Darya means that the flows do not reach the Aral Sea, rather a large portion of the winter water release is now transferred to what is ostensibly a sink – Lake Arnasia.

Attempts to have the countries cooperate around this issue essentially failed, demonstrating that in this case, water transfers did not support broader regional cooperation. But later, according to UNDP, World Bank and Bank Netherlands Water Partnership Program (2003), an Interstate Agreement was signed in 1992 to guide the negotiated cooperation that is needed to re-establish trust and confidence, and facilitate effective management, utilization, and protection of water resources in the Aral Sea basin, and implement joint measures to address the Aral Sea problem. Numerous problems have been encountered during the implementation of these agreements.

This section of the case study highlights (a) the downside of water transfers if the enabling conditions unravel, especially for such a large scale; and (b) the growing recognition of the critical role that cooperation among riparian states can play as an innovative institutional instrument for facilitating faster regional development through co-development, cost and benefit sharing and a shift of focus from water sharing to benefit sharing as a way to redress past inequity in water sharing.

Inter-basin Water Transfer in Spain—Tagus-Segura-Ebro Basins Case Study

The general perception is that it is the government's responsibility to correct the natural hydrologic imbalance, particularly where such imbalance is the main constraint to socioeconomic development of water-scarce areas. In this case study we examine the critical role played by the Government of Spain.

Agriculture is the main economic sector in the Segura Basin, but its performance is constrained by scarcity and variability of both ground and surface water resources. In the 1930s, irrigation expansion plans called for the development of local surface and groundwater and transferring water from the Tagus and Ebro basins. In the 1940s, two dozen reservoirs were constructed with a combined capacity of 1,000 Mm^3 in the Segura Basin and in the 1950s and 1960s; the Government of Spain implemented a program that supported groundwater irrigation.

In 1979, the Tagus-Segura water transfer project with a design capacity of 100 Mm^3 $year^{-1}$ became operational, but only delivered on average 30 Mm^3 $year^{-1}$ due to there being less water available in the Tagus Basin than estimated. However, irrigation continued to expand with the private and unregulated development of groundwater, which in turn led to overexploitation of groundwater aquifers. The government responded to the groundwater overexploitation challenge by the passage of the 1985 Water Law, which set a cap on the number of wells and their discharge. The law was not adequately enforced and groundwater overdraft continued. The irrigated area, which increased from 90,000 to 115,000 ha between 1933 and 1963, jumped to 197,000 by 1983 mainly because of Tagus water transfer in 1979. And by the year 2000, the irrigated area had increased to 252,000 hectares.

In 2001, the Spanish Parliament enacted the Law of the National Water Plan[8] in which 1,050 Mm^3 $year^{-1}$ was to be transferred from the Ebro River, of which 50 % was to be used to reduce water stress in parts of the Segura Basin that were experiencing groundwater overdraft. The Ebro water transfer was strongly opposed by (a) the Government of the Aragon autonomous region located in the Ebro Basin; (b) the people of Ebro delta region; and (c) many environmental groups, scholars and members of civil society. Massive demonstrations

---

[8] The Law of the National Water Plan has several articles that guard against the misuse of the water to be transferred. They include: (a) Article 18 which states that not a single drop of the Ebro River can go to an overexploited aquifer if detailed studies of the situation are not previously performed and approved by the Central Government; (b) Article 29 established the need to carry out comprehensive groundwater studies and to foster the formation of groundwater user groups to spur small-scale hydrosolidarity; and (c) Article 34 seeks to promote good water management and ethics through educational campaigns (Llamas and Perez-Picazo 2001).

against the project took place[9], as those opposed to the water transfer perceived it as a project that threatened livelihoods and ecosystems, ignored environmental directives and mocked the idea of spending public money responsibly. According to Llamas and Perez-Picazo (2001), a poll on the social perception of the Ebro water transfer showed that 50 % of the respondents were in favor of the project and 30 % against. Those in favour were mainly influenced by the common belief in every culture or religion that water should be given to the thirsty. Those against were more influenced by their perception that Segura had more water than it needed if only it could use it more efficiently and productively. Several studies have shown that water demand management would for the time being be a better option to addressing the problems of the Segura Basin than transferring water from Ebro Basin.[10]

The case of the Tagus-Segura-Ebro basins presents facets that appear particularly relevant to the Indian context. The original water transfer, while it seems to have been relatively successful, was seriously compromised by a significant overestimation of the available water, which, among other things, affects the credibility of future efforts to develop transfers. The prevailing financial and market conditions made it attractive for farmers to expand irrigated areas using groundwater. Efforts to regulate groundwater use failed, and a project aimed at providing an alternative water source for the irrigated area and other users within the receiving basin was effectively blocked by the stakeholders in the proposed donor basin, despite a general perception that the project was appropriate.

Long Distance Inter-basin Water Transfer—China's South-to-North Transfer

China's unprecedented economic growth combined with its high population and water scarcity has resulted in increased calls for water transfers from the water surplus southern to the water-scarce northern basins. Feasibility studies on the South-to-North water transfers started

---

[9] For 3 years, thousands of people participated in massive demonstrations. They raised awareness of the negative impacts of water transfers and mobilized support to stop the transfer. They used a wide range of approaches that included: candlelit procession, people chaining themselves outside government offices, holding public meetings, using attention grabbing leaflets, graffiti, concerts, fiestas, puppets and organizing competitions. They mobilized activists from all social strata (category). Fifteen thousand protestors went to Brussels to demonstrate in favor of EU legislation and against their country receiving EU funds (Starbridge 2005).

[10] Albiac (2002) examined water demand management in the Segura Basin as an alternative to water transfer from the Ebro Basin. He considers two water demand management instruments–1) restriction on groundwater use; and 2) increase in water price. He reported that (a) the transferred water would have higher costs, 0.19-0.75 Euro/m^3 higher than current costs and, hence would only be economic for high-value crops; (b) the Segura Basin would only be able to absorb 2.2 Mm3 of the water destined for agricultural use at the water transfer price and not the 3.62 Mm^3 designated in the National Hydrologic Plan to achieve sustainable groundwater management; and (c) subsidy of transferred water would be feasible, but very expensive to the non-agricultural users in Segura. He, therefore, argued that demand management strategy would be preferable, because it guarantees the relief of pressure on aquifers coming from agricultural use without needing to establish strict controls on wells.

in the 1950s and identified three major water transfers (the western,[11] central[12] and eastern[13] route) projects. Environmental impact assessments of the Eastern and Central Route water transfer projects were completed and the projects approved for construction (Shao et al. 2003).

Overcoming Technical Challenges:

Many studies were carried out to identify and address the technical challenges associated with the long-distance of the eastern and central route water transfers. We highlight a few studies to illustrate the technical complexities and technical solutions.

Shao et al. (2003) presented a review of structural problems associated with slope stability, seepage loss and groundwater rise, the settlement of ground surface in the coal mining area, freezing and thawing of the soil and liquefaction of sand in the central route. Mitigation measures were identified and implemented.[14]

Environmental and health hazards were also carefully assessed and addressed. Yin et al. 2001 (quoted by Shao et al. 2003) reported that the diversion from the Hanjiang River into the middle route worsened the eutrophication problem downstream of the diversion point. Sufficient solar radiation during the spring season combined with higher nitrogen/phosphorous loading, low discharge (<500 $m^3 s^{-1}$), slow velocity (<0.8 $m^3 s^{-1}$) and high water temperature (10.5-12.8^{0}C) led to high algae bloom that was recorded in the lower reaches of the Hanjiang River in 1992, 1998 and 2000. Li et al. (2000 quoted in Shao et al. 2003) raised concerns over the possible proliferation of parasitic diseases. They reported that during the period 1989-1998, a total of 7,772 cases of acute schistosomiasis infection were reported in the Hubei Province. Huang et al, .2000 (quoted in Shao et al. 2003) reported that the total area of snail habitat in the Jiangsu Province was 162 km^2, and that inter-basin water transfers can lead to the development of

---

[11] The Western Route diverts water from three major tributaries of the Yangtze River to the Yellow River.

[12] The middle or central route diverts water from the Danjiangkou Reservoir on the Hanjiang River to the Yellow River.

[13] The Eastern Route diverts water from the Yangtze River, stores it in four natural lakes and several planned reservoirs and uses a siphon to cross the Yellow River.

[14] Slope stability problem was expected along 160 km (12%) of the transfer channel. Slope stabilization was achieved using a combination of countermeasures that included: smaller slope angle, vegetated canal banks, drainage ditches, grouting, anchoring and masonry protection. As the transfer canal passes through seven coalmine areas (51 km), surface subsidence, collapse and ground fissures on these areas were anticipated where the effects of coal mining and canal seepage combined. This problem was solved by either re-routing the canal to avoid such a combination or by providing artificial cushion foundation that reduced seepage and soil deformation. Liquefaction and collapse could also occur under seismic shocks if the canal is built on such silty sand base. Preventive measures for this problem included drainage, canal leak proofing, masonry protection, chemical grouting and in some cases deep foundation and anti-earthquake provisions. The presence of water is the main cause of frost heaving and its destructive effect, and consequently drainage and seepage prevention were complementary measures to reinforce the concrete lining of the canal.

snail habitats in the recipient basin. However, as snails cannot survive in the extreme cold climate, the spread of snail habitat north of Biama Lake in Jiangsu Province (above latitude 33^0 15') would be limited.

Analysis of the combined effect of the South-North water transfer and the Three Gorges Project showed that the operation of the two projects together will lead to a slightly longer time and distance of saltwater encroachment up the Yangtze River mouth, during the months of October, November and December (Wu and Wang 2002 quoted in Shao et al. 2003). The operation of the Three-Gorges Dam, the South to North water transfer and the deepwater navigation channel at Shanghai is expected to result in a 10-20 % decrease in sediment discharge into the Yangtze River delta. This may degrade the delta ecosystem with implications on the required level of coastal protection for Shanghai.

This section of the case study illustrates the technical complexities associated with long-distance water transfers and the need to take a holistic view. By combining the effects of water transfers with those of the Three-Gorges Dam, they were able to assess the cumulative effect. It also illustrates that generally there are technical solutions; the problem may be getting the resources to implement them.

Innovative Co-financing Arrangements:

In 1999 there was a shift in China's water policy from structural measures to integrated and holistic approaches (Boxer 2001). This was followed in 2002 by the institutionalization of water rights and water markets. The law provides a framework for promoting sustainable water management through appropriate water rights and licensing systems, river basin management approaches, progressive water pricing and a penalty price for water use that exceeds the allocated quota.

Securing funding for such a massive water transfer project was a major challenge that was further complicated by (a) the fact that water would be transferred from one province to another and in some cases through other provinces; (b) disagreements attributed to the fact that all provinces have their own administrative powers and economic interest; and (c) the fact that water infrastructure is considered to be part of the national infrastructure, and provinces were not keen to finance national infrastructure. An innovative co-financing arrangement was formulated in which (a) the construction of the back-bone infrastructure of the South-to-North transfer is financed through the establishment of a construction fund to cover construction, interest and maintenance costs, which is shared by each province in the form of purchasing water rights (Wang 2001 quoted in Shao et al.. 2003); and (b) each province could raise funds by charging individual users for their water use.

In this section of the case study we note that, just as in the United States of America case study, the water policy reform towards water pricing, water markets and co-financing are creating the appropriate enabling environment. Innovative co-financing arrangements can avail additional resources needed for massive projects; can increase the level of participation, transparency and good governance; and can lower implementation cost, thereby making water transfers more cost-effective. Also, when water users know that they will end up paying for the water transferred they are more likely to fully exploit opportunities for the better management of existing water resources before demanding additional water resources through water transfer schemes.

Transboundary Water Transfer—Lesotho Highland Water Project Case Study

India has less powerful but water-rich upstream neighbors – Bhutan and Nepal. They present opportunities for the co-development of water resources for the benefit of all parties. We examined the Lesotho Highland Water Project for lessons on how upstream and downstream countries can enhance basin-wide benefits through water, cost and benefit sharing mechanisms.

Politics Can Be a Major Stumbling Block:

Lesotho is a land-locked poor country surrounded by South Africa, but it is strategically located in the Drakensberg Mountains, a major water tower for South Africa. South Africa recognized this potential and carried out a reconnaissance study in 1956. This opportunity was revisited by the Government of South Africa following the catastrophic droughts of the mid-1960s. In 1968, South Africa and Lesotho reached an agreement in principle and started consultations, but the negotiation broke off in the 1970s over royalty payment issues. Lesotho Government's support to the black South African struggle for independence strained the relationship between the two countries, and the talks were suspended in 1976. Low-level consultations resumed in 1980 and paved the way for feasibility studies. It was not until the 1986 regime change in Lesotho by a military coup d'etat that the negotiations were concluded. The two conditions that facilitated successful water transfer from Lesotho to South Africa were: (a) the treaty (signed in 1986) that clearly defined the roles and responsibilities of the two states, the strategies for preventing and settling disputes, and facilitated the setting up of governance structures that symbolized cooperation and overcome mistrust; and (b) adequate direct and in-direct benefits that motivated the states' commitment (Mirumachi 2004).

Corruption Can Mar Good Intentions:

The construction of Phase 1A of the project was undertaken between 1989 and 1998 and facilitated the transfer of 0.5 km^3 of water per year from the Orange River to the Vaal River for use in South Africa's industrial province of Gauteng. Phase1B was started and upon completion increased the transfer rate from 18 to 30 m^3 s^{-1}. The project infrastructure affected over 30,000 people, displaced 325 households and led to an ex-closure of 2,300 and 3,400 hectares of crop and grazing land, respectively. The annual royalties that Lesotho receives are estimated to be over US$80 million and accounts for approximately 28 % of the total government revenue (WWF 2007).

The project was expected to cost US$4 billion but ended up costing US$8 billion. Corruption was largely blamed for the escalating costs. In an analysis of what went wrong, Hildyard (2000), highlighted the need to consider the possibility that what went most 'wrong' from the perspective of project-affected people, human rights groups, environmentalists and a range of other civil society groups concerned with accountability, transparency, equity and sustainable development is precisely what went most 'right' from the perspective of those who have benefited institutionally and financially from the project. He argued that taking this approach challenges us to focus less on the perceived 'lack of political will' to tackle corruption and instead focus more on those vested interests that generate immense political will to block investigations when they are initiated and to undermine anti-corruption drives. This will facilitate the analysis of how regulations could be improved and how institutional practices can be changed and empowered to effectively implement anti-corruption regulations. He concluded that (a) the problem of corruption is unlikely to be addressed by new regulations unless and until the well-documented structural and institutional barriers to their rigorous implementation are addressed; (b) addressing institutional and structural barriers requires a major overhaul of the mission, management and culture of institutions, which act so consistently to the detriment of openness, accountability and democratic decision-making processes; and (c) such radical change is unlikely to come about through the goodwill of the institutions under scrutiny and, hence public pressure is a prerequisite for change. These findings are significant not just for India but for all situations where corruption is expected to adversely affect perception over the effectiveness of government investment in such projects.

Challenges in Assessing and Mitigating Environmental Impacts:

The treaty between South Africa and Lesotho included specific environmental conservation and compensation requirements. However, the project started without an Environmental Impact Assessment (EIA). Nevertheless, a full EIA with a proper environmental flow analysis (including examination of the physical, chemical and biological characteristics, and modeling of water quality) was carried out for phase 1B. The EIA raised concerns over critically endangered Maloti minnow, threatened habitats, reduced volume of water for effective dilution of pollutants in the lower reaches of the Orange River and risk of increased de-oxygenation and eutrophication. The utility of the environmental flow assessment was criticised for: (a) lack of legal framework for implementing recommendations; (b) inadequate involvement of the key stakeholders and profession disciplines; and (c) lack of criteria for judging what level of environmental degradation might be considered acceptable by both parties (Watson 2006). Environmental impacts assessment should, therefore, be integrated into various stages of project planning and any concerns addressed by a multidisciplinary and multi-level group of stakeholders, so as to fully incorporate any environmental, social, cultural, economic, legal and political consideration.

Inter-basin Water Transfer—Sao Francisco Interlinking Project, Brazil

Brazil is generally considered to be a water-rich country, but its northern-east region is water-scarce and experiences frequent droughts. The rationale for planning Sao Francisco water transfers is the belief that transferring water from water abundant to water-scarce areas is in the national interest of enhancing socioeconomic development and reducing regional inequity. However, as this case study illustrates, getting a consensus on how to achieve the noble goals of equitable socioeconomic development remains elusive.

The semi-arid areas of north-eastern Brazil are drought prone. According to the International Research Institute for Climate and Society (2005) the area has experienced 28 severe drought years between 1900 and 1999. The effects of many of these droughts are felt for 3-4 years. Drought-proofing the region by transferring water to this region has, therefore, been under consideration for a long time. In 1981, the National Department of Reclamation Works (DNOS) carried out feasibility studies. These formed the basis for the request by the Government of Brazil for the World Bank to finance the preparation of an action plan for the Sao Francisco

Transbasin Project. According to Simpson (1999), the proposed action plan recommended: (a) the full development of local and state water-related institutional capacity before the construction of the Sao Francisco diversion works; (b) establishment of irrigation pilot areas in the plateau of Jaguaribe in Ceará and Apodi in Rio Grande do Norte; (c) establishment of a multi-sectoral entity to develop detailed plans and implement the project; and (d) the requirement that institutional constraints to efficient water use at both the state and federal levels be resolved prior to the project implementation study. In 1989, CODEVASF (Companhia do Desenvolvimento dos Vales do São Francisco) prepared a comprehensive basin plan after a detailed assessment of the needs and potential for development and commercialization of agriculture, hydropower, water supply and wastewater treatment. In 1995, the states of the north-east in cooperation with the National Secretariat of Water Resources formed a group representing water resources sectors of all states to foster water resources legal and institutional cooperation.

In 2000, the government revived planning of the Sao Francisco Interlinking Project. The project aims at enhancing water supply to the over 12 million people and irrigate over 300,000 hectares in the semi-arid region of Pernambuco Agreste and the Metropolitan area of Fortaleza in north-east Brazil. Approximately 99 m^3/s of water was to be transferred from the Sao Francisco River to Ceara, Rio Grande do Norte and Paraiba states that are outside the basin, and a further 28 m^3/s of inter-basin transfer to the Pernambuco states. The project is estimated to cost at least US$2.38 billion and generate jobs for up to 1 million people.

According to Tortajada (2006), the proposed water transfer has the following innovative ideas: (a) the water transferred will be paid for by the receiving state or irrigators; (b) full cost recovery principle will be applied to promote the efficient use of irrigation water; (c) charges for drinking water will be lower corresponding to the so called social rate for the rural population; (d) the volume of irrigation water delivered will depend on the implementation of demand management practices and water-saving technology adopted by the farmers; and (e) negative impacts of water transfers will be reduced. The government has also addressed emerging concerns. Existing water uses are secured and so are the water requirements for energy up to 2025.

Despite all the above assurances and the fact that the project was approved by National Water Resources Council acting on behalf of the Federal Government in February 2006, the construction has been delayed due to (a) the delay in approval by the river basin committee that publicly expressed concerns over the proposed approach and the process followed thus far; (b) the government's decision to shelve the project until after the elections; and (c) concerns raised by various lobby groups such as the use of unrealistic costs and benefits.

Analysis of Case Studies

In this section we analyze the experience of the six case studies and discern lessons that can guide planning, implementation, operation and maintenance of future water transfer projects. We capture issues associated with long distance transfers (China and Aral sea case studies), transboundary inter-basin transfers (Lesotho-South Africa and Aral Sea case studies); inter-basin transfers in a federal government set up (China and Brazil case studies) and within water project and intra-basin transfers (USA case study).

What Are Some of the Impacts?

Hydrologic, Environmental and Socioeconomic Impacts

The literature espousing the hydrologic, environmental and socioeconomic impacts of water transfers is vast (ICID 2006; Das 2006; Gibbins et al. 2000; Snaddon and Davis 1998; and Howe and Goemans 2003), and the case studies highlight the nature and extent of these impacts. In this section we analyze the extent to which the impacts and mitigation measures are identified and adequately assessed.

The impacts can be positive or negative, and their nature and extent varies widely depending on the type and characteristics of water transfer and on other biophysical and socioeconomic conditions (see Table 1). The impacts affect different stakeholders in different locations and in different ways, and have a high temporal variability. And yet, in most cases impacts are presented in a summarized and condensed manner, giving the impression that the impacts are the same everywhere and all the time. Generally, the direct and indirect effect of water transfers on livelihoods;[15] food security;[16] poverty alleviation;[17] health mortality, morbidity

Table 1. Impact categories and effects of water transfers.

Impact category	Effects of water transfer
Hydrologic	Volume, rate and timing of surface flow Seepage transmission losses Evapotranspiration from water bodies Groundwater recharge and discharge Areas of freshwater ecosystems Channel erosion and siltation
Environmental	Reservoir induced seismicity Water quality (physical, biological and chemical pollutants) Soil salinization Waterlogging Desiccation and loss of connectivity of freshwater ecosystems Habitat status Transfers of alien and invasive flora and fauna Invertebrates diversity and quantity Fish diversity and population Disease vectors
Socioeconomic	Changes in value/reliability of benefits derived from in- and off-stream water uses Changes in costs/vulnerability associated with in- and off-stream water uses Displacement and resettlement costs and benefits Costs associated with conflict management Benefits associated with cooperation Multiplier effect of direct benefits arising from water transfer Opportunity cost of investment in water transfer

---

[15] Such as changes in production, employment, processing and trade related incomes.

[16] Such as changes in regional or household food production and market prices.

[17] In terms of number of people who are better or worse off and change in income of the poor.

and health risks; and access and quality of regulating, supporting and cultural services derived from freshwater ecosystems prior to the implementation of the transfer are poorly documented. Third party[18] impacts resulting mainly from loss of farm-related jobs and market opportunities for the goods and services are also inadequately documented. This is partly attributed to the fact that indirect impacts are more difficult to quantify, that they are believed to be minimal and that they are assumed to be naturally mitigated as if the economy is able to self-adjust to create opportunities for those who lose. In other cases the problem may be the ineffectual implementation of mitigation measures.

Impacts on Agricultural Production, Food Security and Poverty

Available literature highlights the complex inter-relationships that determine the nature and extent of both positive and negative impacts and the difficulty in fully identifying the conditions that determine the direction, nature and extent of these impacts. The cause-effect is sometimes difficult to establish, and in some cases, the impacts have been mainly attributed to the broader effects of dynamic changes in the rural and urban economies, such as the declining competitiveness of agriculture in the area (Rosegrant and Ringler 1999).

Transferring water from agriculture can impact a wide range of stakeholders, depending on how dependent they are on the agricultural economy. Transfers can result in changes in the cropping pattern, irrigated area, intensity and productivity. Whereas the recipient and donor of the water may gain through their transactions, other parties may be negatively affected through the reduced water availability and quality. For example, (a) water transfer from rural to urban areas could lower farm employment and demand for rural services and increase them in urban areas; (b) reducing water use in agriculture might positively benefit by improving water quantity and quality downstream to the benefit of fish and other downstream water users; while reducing irrigation drainage outflow might harm flora and fauna dependent on habitats sustained by irrigation return flows. These changes can affect employment opportunities, agricultural incomes, local food self-sufficiency, associated business activities and local and central government revenue. The severity of economic impacts will differ depending on: (a) whether there is adequate economic integration between the source and recipient regions; (b) whether the water donors are compensated or the proceeds from the transfers are invested in the area of origin; (c) economic vitality of the water sources areas; and (d) other spin-off benefits that arise from the transfers.

---

[18] Potential third parties to water transfers include: general taxpayers; urban – (downstream urban uses; the poor urban crop, fish and livestock producers; those employed by companies that would be affected by the transfers); rural (irrigators, fishers and their employees; rural water supply organizations and their employees); and environmental (fish and wildlife habitat and those affected by potential land subsidence, overdraft, water quality deterioration and well interference).

Zhang and Zhang (1995) estimated that in the Yellow River basin, 3 billion cubic meters of urban and industrial wastewater per year has polluted 60 % of its drinking water. Rosegrant and Ringler (1999) reported that in the suburbs of Beijing, both grain output and overall agriculture output value continued to increase at the same time that water had been diverted to urban uses, which resulted a decline in the overall irrigated area.

Where water is being transferred to high-value uses and the water donors are compensated fairly, water transfer has resulted in increases in water productivity and agricultural incomes. In California, Dixon et al. (1993) reported that farmers who transferred some of their water to other uses reduced their operating cost by 11 % and crop sales by 20 %. These reductions adversely affected the suppliers of farm inputs, agricultural workers. Villarejo (1997) in a study on the impact of drought-related water transfers from agriculture to urban areas in Mendota, California reported a 30 %, 14 %, 26 % and 14 % decline in agricultural land value, irrigated area, the number of farms and labor income, respectively. Increased use of low-quality groundwater to compensate for the water transfer to urban areas resulted in a 37 % and 5 % decline in the yield of water melons and staple crops, respectively. Similarly, in the Jordan Valley, the transfer of freshwater to the urban areas and subsequent relatively unplanned transfers that replaced freshwater with reclaimed water has constrained the crops that can be grown in the Middle Valley. For example, stone fruits and vines are susceptible to the relatively high levels of chloride (McCornick, Grattan, and Abu-Eisheh 2003). Those farmers receiving reclaimed water pay half the service fees of those with access to freshwater. A study on the effect of the transfer of 10 % of agricultural water to urban use in San Diego, California reported that the worst case would reduce water for some by as much as 25 %. Such a reduction in water availability would result in a personal income reduction of 5 %, and an increase in average unemployment of the counties of 1.3 %, and in farm employment of 3.9 %.

What Facilitates or Constraints Water Transfers?

The determinants of a water transfer can be grouped into three categories: (a) the natural and human factors that influence the quantity demanded and available supply; (b) the willingness and ability of the water donors and recipients to negotiate and implement the transfer; and (c) external factors that influence the water transfer institutions.

Water Demand and Supply

Water transfer is a response to the growing mismatch between water demand and supply. The water may be transferred to reduce flood damage to a downstream location, but it is generally transferred because there is a water deficit area that can benefit from the excess water available elsewhere. Human needs, how the needs are met and how the available water is managed combine with natural factors to determine water demand and supply. In general, increasing water demand associated with export and local consumption of agricultural produce in a water deficit area increases the demand for water transfer. For example, in the Spain case study, the flourishing agriculture produce export and local trade in the Segura Basin was the main driver of irrigation water requirements and groundwater overdraft.

Willingness and Ability of Water Donors and Recipients to Implement the Transfers

The willingness and ability of water donors to engage in a water transfer scheme depend on the availability of surplus water and the rationale for sharing and exporting water to the water recipients. The easiest water to transfer is the surplus water (renewable water resource less the sum of what is currently and likely to be used in the future and what is required to flow to the river outlet and satisfy other environmental requirements). However, regions/basins with large quantities of excess water are few. Canada, Brazil, Democratic Republic of Congo and Nepal are among the few countries with huge quantities of surplus water. In most other cases, for example, the Mekong Basin, where excess water is available only during the rainy season and huge storage capacities may be required to even the flow. In other cases, the surplus water is not so huge, but opportunities for augmenting it exist through some form of water saving practices, although this is becoming less viable as basin level efficiencies are already relatively high in many basins in the arid and semi-arid parts of the world. The water donors participate in water transfer because of: (a) the direct economic gain as in the case of Lesotho; and (b) indirect gains as part of a grand plan for regional cooperation as in the case of Egypt and Turkey's willingness to transfer water to the Middle East (Dinar and Wolf 1997; Tesfaye 2001), driven by interests beyond the immediate region.

The recipient basin/region will be willing to participate in the water supply if the perceived future benefits are high and the costs of importing water is much less than the cost of water demand management. This is particularly so in the case of transboundary water transfers (see Lesotho case study), but in the case of national water transfers the government may be willing to subsidize the project as in the case of China, Spain, Brazil and the United States, and is effectively a major driver for developing the transfer. We note that while it may be easier to implement a transfer with a strong federal government presence, the long-term sustainability may be more assured with a strong state involvement.

High transaction costs and risks are the two main factors that can dissuade potential partners in water transfer. Transaction costs may include: legal fees; costs of public agency review; costs of required technical studies; and costs involved in settling claims from third parties. Risks may be related to climatic changes, to unilateral actions of water donors that might reduce the amount of water available for transfer, and to structural failure, particularly for long distance water transfers.

External Factors that Influence the Water Transfer Institutions

The main external drivers that we consider are associated with government and lobby groups. In the case of within national water transfer, the level of government commitment and financial support is a major driver as evidenced in the Brazil, China and Spain case studies. In all case studies, federal, state and local governments play a critical role in creating enabling conditions that improve the prospects for water transfers by: (a) improving information and facilitating consultations and negotiations regarding transfers and transfer impacts; (b) ensuring that there is a credible process for managing third party impacts; (c) reducing the transaction costs associated with water transfers; (d) increasing the probability that acceptable water transfer will be successful; and (e) securing funds for the transfers. In most cases these conditions may not be met, leading to sub-optimal performances.

Environmental and civil society lobby groups have also played a key role, particularly in highlighting the negative social and environmental impacts and the need to consider other alternatives to water transfers. Their role is particularly conspicuous in the Brazil and Spain case studies where they challenged the credibility of the costs and benefits of the proposed water transferred, and argued that there were cheaper alternatives in which the government resources could be invested to achieve the same goal but had not been considered.

What Institutional Arrangements Facilitate Transfers Best?

There is growing evidence that water transfer will continue to take place (Tumbare 2001; Davis et al. 1993, ICID 2006). The key question is what institutional arrangement will be required to facilitate the development of environmentally, socially, economically and politically acceptable water transfers. The case studies illustrate that changes in policy, legal and organizational frameworks are needed to: (a) defer water transfers where water demand management options are more economical; (b) secure water rights and facilitate their effective transfers so as to reduce risks and protect the rights of the poor and the environment; (c) protect third parties from the negative impacts of water transfers; (d) facilitate effective consultations and negotiations; and (e) provide incentives for lending agencies and the private sector to participate in water transfers. The precise nature of reform and instruments to be deployed will vary from area to area depending on the relative water scarcity, level of agricultural intensification, nature and extent of negative impacts, level of economic development and organizational capabilities.

Several countries have explicitly incorporated water transfer clauses in their water act and policy. South Africa is a good example. Their water policy states that: *"Inter-basin transfers will have to meet special planning requirements and implementation procedures, which must involve agencies from both donor and recipient catchments. Catchments to which water will be transferred will have to show that the water currently available in that catchment is being optimally used and that reasonable measures to conserve water are in force."* This policy change has influenced the development of water transfer schemes by ensuring that water demand management approaches forestall water transfers and allow available funds for infrastructure investment to be focused on priority areas for service expansion (UNDESA 2005).

At a transboundary level, water transfer should be seen as part of a broader cooperative agreement. In southern Africa, the regional cooperation has created the enabling conditions for consultation and negotiations on water transfers by: (a) having a broader technical, commercial, political cooperation which helps in building mutual trust; (b) having negotiators who can be trusted; and (c) by having a framework for information sharing and research. Given that each basin state is entitled to an equitable and beneficial share of the water and the need to manage it sustainably, river basin institutions should promote understanding and mutual trust between the parties. The parties must: (a) establish potentials and alternative strategies for achieving those potentials; (b) discuss mutual expectations and fears; and (c) negotiate on the most desirable strategies. Long- and short-term river basin plans are needed to adequately define feasible options and prepare the stakeholders to raise their concerns and ensure that they are incorporated in the next basin plans. This can contribute to developing a shared vision and also in opening other opportunities for cooperation such as trade. Such plans can form the basis for improving cooperation (Saddoff and Grey 2005).

What Principles, Approaches and Processes Should Guide Planning?

Successful water transfer schemes are generally considered to be environmentally, economically, socially and politically acceptable. By using accepted principles, correct approaches and effective processes you ensure that major economic, ecological, social, cultural and political issues are adequately addressed.

Water transfer planning should be guided by acceptable hydrologic, ecological, economic and social principles. Most of these are already an integral part of water resources planning and management. The case studies illustrate the need to take into consideration all the principles and, specifically, the solidarity[19] and precautionary[20] principles.

Many water transfer projects have been criticized for failing to take a holistic approach to problem, opportunities and solution analysis. For example, the Brazil case study illustrates a failure to explore other options to achieve the desired socioeconomic development and only focus on water transfer as the main driver of economic development. In the Spain case study, it was argued that water-demand management would be more cost-effective than augmenting water by water transfers. In the case of the Aral Sea water transfer, some of the contentions revolved around the reservoir operating policy and its effect on the benefits derived from hydropower and irrigation and as to who received the benefits. We, therefore, argue that using the correct approaches will improve the changes in planning acceptable water transfers.

Water transfers generally take a long time to accomplish. The processes followed in the pre-feasibility, feasibility, design, implementation and operation and maintenance should ensure continuity, and have an inbuilt flexibility to take into consideration new insights, data and analytical tools. The processes followed should take into consideration the fact that water transfers issues are shaped by the context, information, assessment, consultation and negotiation. Regular and well-structured debates should be part of the processes that help clarify and agree on the vision, goals, targets, problems and opportunities, possible interventions, criteria to be used in selecting the most appropriate interventions and the required monitoring, evaluation and adaptive management. We surmise that most water transfer controversies can be resolved by using the right process, at the right time and within the right context. Such idealistic conditions can only be achieved through a gradual process of adaptive management.

---

[19] Principle of solidarity – Solidarity of those who have the resource and give it up to those who lack it, thereby contributing to the creation of employment and wealth creation for the country/region that is beneficial for all.

[20] The Precautionary Principle is also reflected in Principle 15 of the United Nations Conference on Environment and Development (UNCED): it states that 'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

How Can Research Contribute?

Water transfer controversies are generally fuelled by lack of a good understanding of the complex system, and how water transfer will impact people and the ecosystems they depend on. The primary responsibility of research is to improve stakeholders' understanding of the economic, ecological, social, cultural and political issues associated with water transfers, and present feasible solutions to the problems that may emerge. Other important contributions are developing tools and methods for generating and applying information on contentious issues such as: (a) dispelling the myths; (b) risk and uncertainty associated with human behavior, politics and climate change; and (c) water and water-related benefit sharing. In practice, this is not happening, partly due to the disconnection between researchers and those involved in planning and implementing water transfer projects.

Conclusions and Lessons for the NRLP

Conclusions

The case studies illustrate the fact that the water transfer context changes. First, changing political, governance and trade contexts create opportunities and challenges for shifts from unilateral to cooperative actions. The shift from water sharing to hydro-solidarity, best joint utilization and benefit sharing is also providing additional impetus for cooperative actions. Under cooperative action, water transfer schemes are more acceptable in keeping with the solidarity and benefit sharing concepts. Second, land use intensification (in situ moisture conservation, runoff control, small dams) is increasing evapotranspiration and groundwater recharge resulting in unplanned/unintended water transfers. Third, there is a growing recognition of the high potential for areas experiencing water scarcity to use demand-management approaches instead of relying on inter- and/or intra-basin water transfers. Virtual water transfer can increase or decrease the demand for water transfers, depending on what the recipient basin imports and exports and its water demand implications. In all cases, there is a need for rigorous planning that considers the likely trajectory of water use, what can be realistically expected from demand-management and other non-physical interventions, and develop reasonable plans for the prudent development of transfers, where appropriate.

In situations where there are suitable sources of surplus water and a growing demand in a water deficit area, it is not a question of whether the transfer will occur or not, but rather when, and how much water will transfer and how to implement the transfer in ways that reduce negative impacts. We, therefore, argue that good economics (benefits higher for all), good politics (reduce conflicts, assess whether plans will yield equitable and reasonable benefits) and good environmental management are pre-conditions for acceptable water transfers. Achieving this is generally not easy as illustrated by the case studies we reviewed.

Based on the analysis of the case studies, we surmise that water transfer schemes are more likely to succeed where: (a) the recipient basin/area is utilizing its water efficiently through appropriate demand-management, and that the proposed water transfer is the most cost-effective means of securing additional water; (b) the donor basin has enough water to meet its current and future needs (including environmental) and a surplus that can be transferred; (d) environmental and social costs in the areas donating and receiving the water and in the areas/facilities linking the exporting and receiving areas can be reduced to acceptable levels; (d) cooperation and benefits sharing arrangements that result in a 'win-win' or at least 'win-no lose' situations can be established; and (e) the processes and structures create an enabling environment for effective consultation and negotiations and for more effective strategic and pro-active approaches to address emerging challenges and opportunities.

Lessons for the NRLP

The key lessons for the NRLP are:

1. A wide range of water transfer options exist depending on the objectives, geographical scope, route, arrangement and operation criteria of the water transfer scheme. This increases the flexibility of integrating water transfers with other water management strategies and of implementing water transfers in the most prudent ways.

2. In most cases, cost-effective mitigation measures now exist but have not been highlighted in the planning stages nor implemented in part because the approaches proposed are viewed as unrealistic and burdensome by the decision makers, and also because the incentive structures for and political interest in large-scale developments dissipates once they are operational. The subsequent non-performance of the mitigation measures and inadequate information on the positive effects of the project after development, results in a general negative perception of the impact.

3. High transaction costs and risks are the two main factors that can dissuade potential partners in water transfer. Transaction costs may include legal fees, costs of public agency review, costs of required technical studies and oversight of the implementation, and costs involved in settling claims from third parties. Risks may be related to politics and associated conflicts, to climatic changes, to unilateral actions of water donors that might reduce the amount of water available for transfer, and to structural failure particularly for long distance water transfers.

4. Water transfer options can only be explored comprehensively and their acceptability negotiated if there is an enabling environment. The following institutional changes may be required: (a) legislation that stipulates that the minimum flow requirements of the donor basin are met, and that the recipient basin must prove that it has used every reasonable method to develop and conserve its own resources before looking outwards; (b) creation of the offices of environmental and water transfer ombudsman through which grievances may be aired and credible information sought and effectively used to inform consultations and negotiations; (c) use of innovative water transfer arrangements such as water banks and markets; and (d) appropriate water, cost and benefit sharing arrangements.

5. Effective planning, design and implementation are constrained by inadequate understanding of the system, and how it is likely to respond to hydrologic changes induced by the water transfer. The process is further constrained by: (a) lack of

comprehensive impact studies, follow up monitoring and adaptive management; (b) inadequate coordination of environmental, engineering and socioeconomic studies; (c) geographic or issue bias depending on data availability and political influence; and (d) the divergence of opinions, and in some cases reluctance to change, between those for and those against the transfer. Tools and methods are needed to improve the understanding of such complex systems and their responses and to facilitate the use of credible information in the complex consultation and negotiation processes. Guidelines on how to plan, design and implement acceptable water transfer schemes would ensure that consistent approaches and methods are applied and, thereby increase the chances of arriving at a consensus on water transfer impacts.

References

Albiac J. 2002. Water Demand Management versus Water Supply Policy: the Ebro River Water Transfer. World Bank Water Forum 2002 Inter-Basin Transfers May 6-8, 2002.

Berkoff, J. 2003. China: The South – North Water Transfer Project – is it justified? *Water Policy 5*: 1 – 28.

Boxer, B. 2001. “Contradictions and Challenges in China’s Water Police Development.” *Water International* 26 (3): 335–341.

Changming Liu and Hongxing Zheng, 2002, South- to- north water transfer schemes for China. *Water Resources Development* 18 (3): 453 – 471.

Comprehensive Assessment of Water Management in Agriculture. 2007. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earthscan, and Colombo: International Water Management Institute.

Davies, B. R.; Thoms, M.; Meador, M., 1992. The ecological impacts of inter-basin water transfers: and their threats to river basin integrity and conservation. *Aquat. Conserv.: Mar. and Freshw. Ecosyst*. 2: 325-349.

De Silva, K. M. 2005. A history of Sri Lanka. Penguin Books, India.

Deepak Kumar Das, 2006, Environmental Impact of Inter-Basin Water Transfer Projects: Some Evidence from Canada. *Economic and Political Weekly XLI* (17):1703 – 1707.

Dinar, A.; Wolf, A., 1997: Economic and Political Considerations in Regional Cooperation Models. *Agricultural and Resource Economics Review.* April 22, 1997. pp 7-22.

Dixon, L.S.; Moore, N.Y.; .Schechter, S.W. 1993. California’s 1991 drought waterbank: Economic impacts on the selling regions. Santa Monica: Rand.

Griffin, R. C.; Boadu, F. O. 1992. “Water Marketing in Texas: Opportunities for Reform.” *Natural Resources Journal* 32 (1992): 265-88.

Hildyard N. 2000. The Lesotho Highland Water Development Project What Went Wrong? A paper presented to the Conference: “Corruption in Southern Africa - Sources and Solutions”. Held on July 10th 2000 at Chatham House, London.
http://www.globalpolicy.org/nations/corrupt/lesotho.htm

Howe, C. W.; Goemans, C. 2003. Water Transfer and Their Impact: Lessons from Three Colorado Water Markets. *Journal of American Water Resources Association (JAWRA)* 39(5): 1055-1065.

ICID. 2006. Experiences with inter-basin transfers for irrigation, drainage and flood management. Revised draft report of the ICID task force on inter basin water transfers. New Delhi, India: International Commission on Irrigation and Drainage.

Johns G. 2003. Where is California Taking Water Transfers? *Journal of Water Resources Planning and Management* 129 (1) *January*/February 2003.

Kemper, K.; Azevedo, G.; Baltar, A., 2002. São Francisco River Inter-Basin Transfer Project Brazil. Presentation made during the World Bank Water Forum held in Washington D.C., May 2002.

Libecap, G. 2005, The Problem of Water, Workshop on New Institutional Economics and Environmental Issues, Workshop on Environmental Issues and New Institutional Economics, INRA-ENESAD CESAER, December 8, 2005. Dijon, France.

Llamas, M. R.; Pérez-Picazo, M. T. 2001. The Segura Catchment Management and the Debate on Hydrosolidarity in Spain. Proceedings SIWI Seminar on Water Security for Cities, Food and Environment - Towards Catchment Hydrosolidarity held in Stockholm, August 18, 2001

Lund, J. R.; Israel, M., 1995. Water Transfers in Water Resources Systems. *Journal of Water Resources Planning and Management* Vol. 121, 193-204.

McCornick, P. G.; Grattan, S. R.; Abu-Eisheh, I. 2003. Water Quality Challenges to Irrigated Agriculture Productivity in the Jordan Valley. In *Water for a Sustainable World – Limited Supplies and Expanding Demand*, eds. A.J Clemmens and S. S. Anderson. United State Commission on Irrigation and Drainage. pp. 333-344.

McKinney, D.C. 2003. Cooperative management of transboundary water resources in Central Asia. http://www.ce.utexas.edu/prof/mckinney/papers/aral/CentralAsiaWater-McKinney.pdf (Accessed on August 20, 2003).

Micklin, P. P. 1988. Desiccation of the Aral Sea: A Water Management Disaster in the Soviet Union. *Science* 241, 1170–6.

Mirumachi, N. 2004. Incentives for Cooperative Water Management in International Rivers: The Case Of The Lesotho Highlands Water Project

Nieuwoudt, W.L. 2000. Water Market Institutions in Colorado with possible lessons for South Africa. *Water SA* vol. 26 No 1. January 2000.

Rakesh, T. 2006. River Water Sharing Issues: Conflicts over International Waters. *Economic and Political Weekly* XLI (17):1684 – 1692.

Rende, M. 2004. Water Transfer from Turkey to Water Stressed Countries in The Middle East.

Rosegrant, M. W.; Ringler, C., 1999. Impact on Food Security and Rural Development of Reallocating Water from Agriculture. Environment and Production Technology Division Paper 47 Washington, D.C. IFPRI,

Gupta, S. K.; Dinesh Kumar, M. 2004. Dynamics of Inter-Basin Water Transfer: Lessons from Sardar Sarovar Narmada Project. *Jalvigyan Sameerksha* 19 (1-2): 89-104.

Shah, T.; Amarasinghe, U.; McCornick, P. G. 2007. India’s River Linking Project: The State of the Debate. Draft prepared for the IWMI-CPWF project “Strategic Analysis of the National River Linking Project of India”

Shao, X.; Wang, H.; Wang, Z. 2003. Inter-basin Transfer Projects and Their Implications: A China Case Study. *Intl. J. River Basin Management* 1 (1): 5–14 (2003).

Snaddon, K.; Davis B.1998. An Analysis of the Effect of Inter-basin Water Transfers in Relations to the New Water Law. Final Report presented to Department of Water Affairs, Government of South Africa. Pp.50.

Starbridge, S. 2005. Spain’s Ebro Transfer - A major turnaround. http://www.panda.org/about_wwf/what_we_do/freshwater/problems/infrastructure/water_transfers/ebro_transfer/index.cfm

Tafesse, T. 2001. The Nile Question: Hydropolitics, Legal Wrangling, Modus Vivendi and Perspectives / Tesfaye Tafesse. – Munster: Lit, 2001.

Tortajada, C. 2006. São Francisco Water Transfer Occasional paper of UNDP, Human Development Report office. 2006/49.

Trans-Texas Water Program 1998: southeast area: planning memoranda: equity issues related to water transfers, southeast area.

Tumbare, M. J. 2001. Management of Shared Watercourse Systems in the Southern African Development Community Region

UNDESA. 2005: Good Practices in Agricultural Water Management: Case Studies from Farmers Worldwide. Paper presented during the 13th Session of Commission on Sustainable Development held on 11-22 April 2005 in New York. Background. Paper No. 3 DESA/DSD/2005/3.

UNDP, World Bank and Bank of Netherlands Water Partnership Program. 2003. Stakeholder Involvement in Options Assessment: Promoting Dialogue in Meeting Water and Energy Needs. A Sourcebook

World Bank. 2004. Water Resources Sector Strategy: Strategic Directions for World Bank Engagement. World Bank, Washington D.C., USA: the World Bank.

World Bank. 2005. Pakistan Water Resources Assistance Strategy. Water Economy: Running Dry. Report No. 34081-PK, Agriculture and Rural Development Unit, South Asia Region, World Bank, Washington D.C., USA: the World Bank.

WWF. 2007: Pipedreams? Inter-basin water transfers and water shortage. A report of the Global Freshwater Programme of World Wildlife Fund.

Zeitoun, M.; Warner, J. 2006. *Water Policy* 8 (5): 435–460. IWA Publishing.

Appendix 1.

Impacts by Zones

Zone	Hydrologic changes	Environmental	Social-economic
Water contributing area in the donor basin		Barrier to migration of fish species Loss of some species	
Zone downstream of the diversion point	Reduced flows	Sedimentation Down-cutting of tributaries due to decreased base flow Higher concentration of pollutants Increased geostatic loading (seismicity) Reduced availability of important fish food organisms	Reduced fish catches Reduced flood plain usage Loss of flood plain agriculture
Water transfer route zone	Increased seepage loss and groundwater recharge	Water quality deterioration in open canals Salinization due to seepage Transfer of disease vectors and pathogens Increase mosquito habitat Introduction of alien species	Increased health risks Loss of or damage to sites of archaeological, historical and cultural values Loss of homelands and culture of indigenous people
Zone below water transfer point in the recipient basin	Increased flow and changes in seasonality of flows Heightened flood peaks Increased groundwater level	Reduced bank stabilization as a result of increased flows Reduced deterioration of estuarine and inland sea system Increased sedimentation Dilution of effluents	Increased flood plain usage Loss of homelands and culture of indigenous people
Zone upstream of water transfer in the recipient basin			
Other outside these zones but dependent on goods and services derived from these zones.			

Linking Rivers in the Ganges-Brahmaputra River Basin: Exploring the Transboundary Effects

Anik Bhaduri[1] *and Edward Barbier*[2]
[1] *International Water Management Institute, New Delhi, India*
[2] *University of Wyoming, Wyoming, USA*

Introduction

Concerns over transboundary freshwater transfers have sparked increased research into international river basin cooperative management (e.g., see Beach et al. 2000; Biswas 2001; Dinar and Dinar 2000 and Just and Netanyahu 1998). A growing number of studies have focused on bilateral and multilateral cooperative water agreements as potentially efficient mechanisms (Bennett et al. 1998; Dinar and Wolf 1994; Just and Netanyahu 1998; Kilgour and Dinar 2001; Rogers 1993; Wolf 2005; Alexender et al. 2004). These studies also indicate that water transfers, the diversion of water from a water-surplus part of a river basin to one or more water-deficit areas, could prove a useful way of augmenting existing water-sharing treaties for an international river basin, especially when growing water demands threaten the long-term viability of the agreements. For example, Just and Netanyahu (1998) show that cooperation in international river basin management can be strengthened through 'linking' any agreement between the parties to an additional issue of mutual interest to the parties. Similarly, Bennett et al. (1998) demonstrate how issue linkage can facilitate agreement on a number of international river basin issues, and strengthen the enforceability of existing agreements.

The following article contributes to this literature by examining the scope for linking the existing bilateral agreement between India and Bangladesh on sharing water from the Ganges River to an additional provision allowing for mutually beneficial water transfers from the Brahmaputra River. The article provides a modelling framework for analyzing the bilateral decision to cooperate on such water transfers, which also provides the basis for analyzing the conditions under which both countries would agree to such transfers. Such a framework, although relying on the specific case of water sharing between India and Bangladesh, is potentially relevant to many other river basins where international cooperation in river basin management and water transfers may play a significant role.

To understand the importance of the Brahmaputra water transfer proposal to the existing bilateral agreement between India and Bangladesh on sharing water from the Ganges River, it is necessary to explore further the background to transboundary water sharing of the Ganges River.

The Ganges River originates in China, and along its 2,500 km long course, the river flows through northern India and passes through the state of West Bengal in India and then enters Bangladesh. In central Bangladesh, the Ganges is joined by the Brahmaputra and Meghna rivers before the combined flows empty into the Bay of Bengal (see Figure 1). In Bangladesh, which is the final downstream country along the Ganges, freshwater availability depends on the share of water diverted by India, which is the next country upstream. For many decades, India and Bangladesh failed to resolve issues of sharing the water of the Ganges River, particularly the dry season flow.[1] In 1996, a major treaty (The Ganges River Treaty) was signed between India and Bangladesh to resolve the water allocation dispute. The treaty was based on the existing flow of water in the Ganges River.

Unfortunately, however, the rapidly increasing populations of both India and Bangladesh are already leading to a shortage of surface water flows in the Ganges River relative to the rising demand.[2] However, while there is a shortage of flows in the Ganges to meet the future

Figure 1. Map of India and Bangladesh showing major rivers.

---

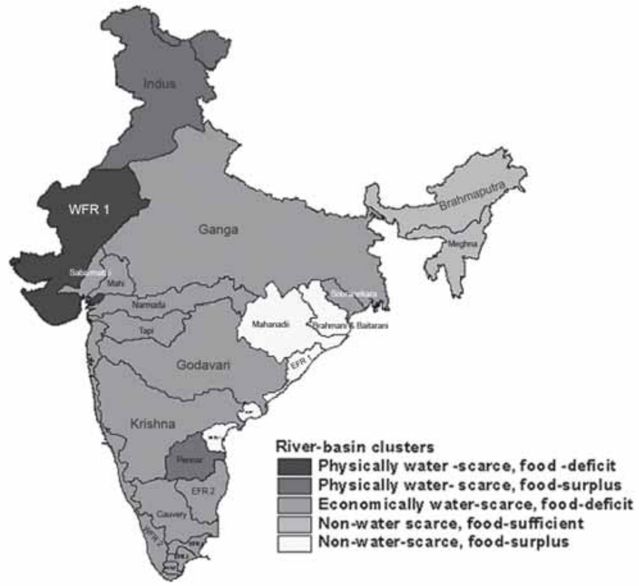
[1] For a complete history of the dispute between India and Bangladesh over sharing the water of the Ganges River, see Crow et al. (2000), Nishat and Faisal. (2000), Hossain (1998) and Khan (1996).

[2] As summarized by Shah (2002, pp. 40-41): “The flows at present available in the various tributaries and the main river are totally inadequate to meet the requirements of the remainder of the irrigation potential of about 41 million ha. The present population in the Ganges portion of India is about 400 million, and this is expected to increase to about 550 million by the year 2010. Consequently, the demand of water for various purposes, including domestic, municipal, livestock, and agriculture, will progressively increase every year.” See also Amarasinghe et al. (2005), who examine the spatial variation of the available water resources (see Figure 2) and estimate that much of the peninsular river basin is water-scarce with the availability being less than 20 billion cubic meters (BCM). In comparison, the total annual water withdrawal estimate in India is 650 BCM.

requirements of both India and Bangladesh for water, there is likely to be a surplus of water available in the neighboring basin of the Brahmaputra River. For example, it is estimated that in-basin utilization of the Brahmaputra accounts currently for only 4 % of the available surface flow (Shah 2001). Thus, trans-basin transfers of water from the Brahmaputra to the Ganges has been proposed as a potential solution to the imminent water shortage in the Ganges River basin and as a means to forestall possible future water conflicts between India and Bangladesh.

There are good reasons why India is particularly interested in such a water transfer scheme. A significant part of the water resources of India lies in the Brahmaputra River, which is in a remote corner of the country and far from the areas where the demand for water is high (see Figure 2). The Brahmaputra River accounts for 29 % of the total runoff of all of India's rivers, representing a potential source of available water. Currently, India is planning to develop a National River Linking Project (NRLP) and divert surplus water from the Brahmaputra River to alleviate shortages in western and southern India (Iyer 2003). India intends to transfer water from Brahmaputra through a gravity link canal taking water from Jogighopa in India, and joining the Ganges River just above Farakka (see Figure 3). The link is proposed to transfer 43 billion cubic meters (BCM) of water from the Brahmaputra River, of which 15 BCM is to be transferred to the Ganges River at Farakka (Thakkar 2007). The augmented water at Farakka would then be shared between the peninsular river basins in southern India and water flows to the downstream of Ganges River in Bangladesh.[3]

Figure 2. Spatial variation of available water resources in India's river basins.

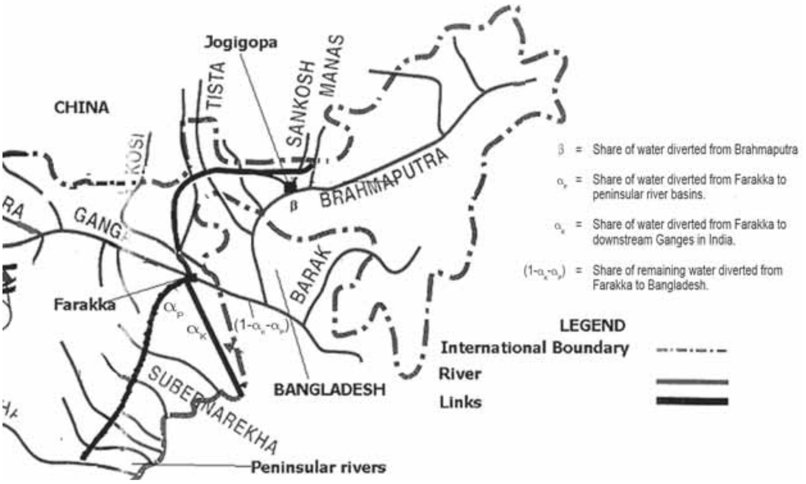


Source: Amarasinghe (2005)

---

[3] The interlinking of rivers in peninsular India involves Mahanadi, Godavari, Krishna Cauvery and Pennar rivers.

Figure 3. Proposed river link from Brahmaputra (Jogigopa) – Ganges (Farakka).



Source: National Water Development Agency, Government of India

Under such a water diversion scheme, diversions from the Brahmaputra to the Ganges would, therefore, be made entirely within India.[4]

However, there are several concerns about such a proposal for the downstream country, Bangladesh. Diversions of large amounts of water, above a certain threshold level, from the Brahmaputra River upstream in India could disrupt the lean season flows and ecology of the downstream Brahmaputra River in Bangladesh.[5] Of particular concern is the increased likelihood of an environmental catastrophe in Bangladesh because of the salinity ingress that could arise from the depletion of water in the downstream Brahmaputra. There are also fears in Bangladesh that construction of a dam at Jogighopa would provide India an additional opportunity to control the entire amount of water flowing into Bangladesh, where currently nearly 20 million Bangladeshi small farmers depend on river water that flows through India for their cultivation.

On the other hand, if India diverts an amount of water below the threshold level, then Bangladesh could benefit, as the surplus water from Brahmaputra, which creates frequent floods, can be diverted to meet the excess demand of water in the Ganges River basin. Even in a normal

---

[4] In the past, India had made several attempts to persuade Bangladesh to agree to a proposal to augment the flow of water of the Ganges River at Farakka through transferring surplus water from the Brahmaputra River. Previously, India proposed constructing a 200-mile long canal that would transport the water to the Ganges at a point just upstream of the Farakka Barrage. However, this canal would have occupied 20,000 acres of agricultural land in Bangladesh. As a result, the Bangladesh Government rejected the Indian proposal. Hence, the current proposal by the Indian Government involves redesigning the construction of the canal, so that the transfer of water from Brahmaputra would take place entirely within Indian Territory. See Shah (2001).

[5] Bangladesh Government scientists claim that 10 to 20 % reduction in the water flow of Brahmaputra to the country could dry out great areas for much of the year (Rahman 2005).

year, about 20 % of the country is inundated, but in extreme years the area of inundation may rise up to 60 % (Ahmed et al. 2006). For example, the 1998 floods in Bangladesh covered more than two-thirds of the country and lasted 59 days, resulting in 918 deaths, the displacement of over a million people, and caused 2.04 million metric tonnes in rice crop losses (10.45 % of target production in 1998/99) as well as other economic damages (Ninno 2001). Thus diversion of surplus water would reduce the flood-related damage caused by the Brahmaputra in Bangladesh, while at the same time augment the flow at Farakka to ensure sufficient surface flow in the downstream Ganges River to meet the growing water needs of Bangladesh.

Unfortunately, the existing Ganges River Treaty contains no provisions to augment the flow of the Ganges River, through regional cooperation to transfer water from a separate river basin, such as the Brahmaputra. Thus India and Bangladesh would have to negotiate and sign a separate agreement to establish an appropriate sharing of the augmented flow of the Ganges River through water transfers from the Brahmaputra River. A key issue, therefore, is whether it is in the interest of both India and Bangladesh to agree mutually to such a water augmentation agreement.

To explore the implications of this issue, and thus the feasibility of such an international river basin agreement on water transfers, in the next section we develop a two-country river basin model of upstream-downstream water allocation, with the possibility of water augmentation. We show that water transfer from the Brahmaputra River could be mutually beneficial for both countries. However, the only possible motivation for the richer upstream country, India, to agree to transfer water to the poorer downstream country, Bangladesh, is political altruism: If there is a good political relationship between India and Bangladesh, then India could be altruistic towards Bangladesh and transfer more water downstream. Changes in the political altruism factor, however, could entice India to exercise unilateral diversion, in which case simulations predict that Bangladesh would incur large environmental damages.

A Model of Water Sharing between India and Bangladesh

In this section, we develop a model of water allocation for the Ganges-Brahmaputra –peninsular river basin to assess the impacts of the additional supply of water from Brahmaputra on the benefits accrued to India and Bangladesh.

India and Bangladesh are represented in the model as superscripts by superscripts 1 and 2 respectively, while the Ganges and Brahmaputra and peninsular river basin are denoted by subscripts G and B and P, respectively.

Consider the amount of water available in the upstream Ganges (at Farakka) and the peninsular river basins in India as W_G and W_P, respectively. Similarly, the flow of water of the Brahmaputra River in India at the point of diversion (Jogighopa)[6] is W_B. After the construction of the dam at Jogighopa, India has the opportunity to now determine the share of water (β) diverted from the Brahmaputra River. The proportion of water diverted from upstream Brahmaputra in India is β and the remaining $(1-\beta)$ proportion flows in the downstream Brahmaputra River basin in Bangladesh. β strictly lies between 0 and 1. We also assume that

---

[6] The point where India constructed a dam on the Brahmaputra River to divert water through a link canal.

the proportion of water allocated to Indian downstream of the Ganges River and peninsular river basin at the point of the diversion (Farakka) are α_G and α_P , respectively.[7] The remaining water flows in the downstream Ganges to Bangladesh. The total supply of water in downstream Ganges River and peninsular river basin in India, respectively, are as follows:

$$S_G^1 = \alpha_G [W_G + \beta W_B] \quad \text{and} \quad S_P^1 = \alpha_P [W_G + \beta W_B] + W_P \qquad (1)$$

The total supply of water in downstream Ganges River basin in Bangladesh is represented as

$$S_G^2 = (1 - \alpha_G - \alpha_P)[W_G + \beta W_B]; \qquad (2)$$

while the total supply of water in downstream Brahmaputra River basin in Bangladesh is

$$S_B^2 = (1 - \beta) W_B \qquad (3)$$

Every year Bangladesh incurs heavy losses from flood-related damages. Examples of such flood-related damages include loss of human life, loss of crops and damage of properties. There would be a reduction in flood-related damages after the diversion of surplus water from Brahmaputra. The flood-related damages incurred by Bangladesh, represented by *D*, were caused by surplus water in downstream Brahmaputra River and can by characterized by the following function:

$$D = D[(1 - \beta)W_B] \text{ For } \beta < \hat{\beta} \text{ with } D'(\beta) < 0, D''(\beta) < 0 \qquad (4)$$

$$D = 0 \text{ for } \beta \geq \hat{\beta}$$

We assume that the damage caused by floods in the Brahmaputra Basin, *D*, decreases with the increase in the share of the diversion of water (β) to the Ganges Basin. We also assume that there would be no flood-related damage if the level of water diversion ($\hat{a}$) equals or exceeds a threshold level ($\hat{\beta}$).

The diversion of surplus water from Brahmaputra could initiate a process of environmental degradation in Bangladesh. If the share of water diverted from Brahmaputra exceeds a certain threshold level, we assume that the reduced water levels in the downstream Brahmaputra River could cause environmental losses. Less water in the downstream could disrupt fishing and navigation, and also could bring unwanted salt deposits into rich farming soil. More water diversion of silt-free water in the upstream could allow greater saline intrusion into Bangladesh, and change the hydraulic characteristics of the river. It could affect the ecology of the delta.

The environmental damage to Bangladesh can be expressed by the following function

$$L = 0 \text{ for } \beta < \tilde{\beta}$$

$$\text{and } L = L(\beta) \text{ for } \beta \geq \tilde{\beta} \text{ with } L'(\beta) > 0, L''(\beta) > 0 \qquad (5)$$

---

[7] Under the case where there is no provision to transfer water $\alpha_P = 0$

We assume that if the share of water diversions by India in the upper Brahmaputra crosses a threshold level ($\tilde{\beta}$), there would be consequential environmental losses, which will further increase with the increase in the share of water diverted from the upstream Brahmaputra (β)**.** Sinc**e** such environment losses generally take place at a much higher share of water diversion, we assume that the threshold level for environmental damage ($\tilde{\beta}$)is higher than that of the threshold level, ($\hat{\beta}$) , above which there exists no flood control damage.

Water transfer from Brahmaputra may produce positive externalities in the form of additional benefits to India. The benefits mainly include hydropower generation, and navigation. The dam at the point of diversion (Jogighopa) could help India to generate hydroelectric power for the northeastern part of the country.[8] India can also use the link canal for navigational purposes, to connect the remote areas of the country in the northeast to the mainland. The benefits can affect India's welfare and may alter the water sharing allocation. The benefit function, G, is dependent on the total water transfer (βW_B). The additional benefits to India as a result of diversion of water from Brahmaputra River can be represented by:

$$G = G(\beta) \text{ with } G_1'(\beta) > 0, \mathrm{G}_1'(\beta) > 0. \qquad (6)$$

India incurs the cost of constructing a dam on the upstream Brahmaputra to divert water and also to construct the interlinking canal. Transfer of water entails a high cost, which may include building storage dams, canals or pipelines. The presence of the transfer cost of water is crucial to the outcomes of the model. The marginal cost of diverting each unit of water is assumed to be convex, denoted by:

$$r(\beta) \text{ where } r'(\beta) < 0 \text{ and } r''(\beta) > 0\ .^{9} \qquad (7)$$

Though initially India will incur a huge cost for the construction of dams, the unit cost will decline with the increase in the share of water diversion.

We assume the benefit function from water use for each country is concave and there exists an interior solution. Although both countries are likely to obtain multiple benefits from water use, we solely consider the production benefits of the only agricultural sector in our model, as nearly 70-80 % of the water is used for irrigation in the region. Consider the agricultural production in country i (i=1, 2) and river basin j (j=G, B, P) is $q^i_j(\omega, m)$ where ω is theconsumptive usage of water and m is the vector of other inputs used in the agricultural production. The farmers in each country sell the crops at a vector of price p (i=1, 2)[10] and the marginal cost of agricultural production is c.

---

[8] India 's national water development agency, which is backing the interlinking of rivers scheme, has said it will divert enough water to produce 34,000 megawatts of hydroelectricity (Government of India 1999).

[9] As water flow in the Brahmaputra River, W_B is deterministic, we assume the marginal cost of water transfer is independent on flow of water at Jogighopa.

[10] p is exogenously determined in the international market.

Prior to the inter-linkage of the rivers in two river basins, India's benefit function can be represented by the following equation:

$$B_0^1 = (p - c)[q_G(\omega_G^1, \mathrm{m}^1) + q_P(\omega_P^1, m^1)]. \qquad (8)$$

In the peninsular river basin, the physical water availability constraint is binding and the consumptive usage of water is determined by the available supply of water. The water constraint in the peninsular river basin, prior to transfer of water from Brahmaputra is $\omega^1_p = S^1_{\mathrm{p}} = W_p$

In the case of the Ganges Basin, if there is no treaty between India and Bangladesh, India diverts a share of water to meet its optimal water consumption needs.

India will determine the optimal share of water diversion upstream by choosing α to maximize its benefit function given in equation 8, and the constraint $\omega^1_G = \alpha W_G$ $\alpha \in (0,1)$.

The first order condition of the above problem can be represented as:

$$\left[(p - c)\frac{\partial q_G{}^1}{\partial \omega_G}\right] = 0 \qquad (9)$$

The above expression implies that India's payoff will be maximized when the net marginal benefit of water consumption is equal to zero.

Suppose the solution to the above maximization problem is $\alpha_0{}^*$. Since B^1 (W^1) is strictly concave, it follows that the slope of the benefit function with respect to the share of water diverted is positive for $\alpha < \alpha_0{}^*$, and conversely, is negative for $\alpha > \alpha_0{}^*$. Assuming that the consumptive usage of water is a fixed proportion of the available water, α, a lower rate of water utilization would require a lower value of α, thus under-utilization of water for a lower value of α will result in lower profit for producers. Similarly, over-utilization of water will ensure a lower profit $B^1_0 < B^1_0{}^*$ because of diminishing marginal productivity of water and the negative second-order profit condition. Given that there is no water sharing agreement; India will maximize its agricultural profit $B^1_0{}^*$ by diverting $\alpha_0{}^*$ share of water in the upstream and allowing the rest to flow downstream to Bangladesh.

The freshwater availability of the downstream country, Bangladesh, is dependent on the share of water diverted by the upstream country, India. Bangladesh's benefit from water would be:

$$B_0^2 = (p - c)[q^2_G(\omega^2_G, m^2_G) + q^2_B(\omega^2_B, m^2_B)] - D(W_B) \qquad (10)$$

As Bangladesh's water consumption in the downstream Ganges River basin is determined by India' optimal decision to share the water at Farakka, Bangladesh's problem would be only to maximise the agricultural benefits in the Brahmaputra Basin by choosing the optimal water consumption level, ω^{*2}_B, in the latter basin.

In the scenario, where India has the opportunity to divert surplus water from Brahmaputra, the benefit function of India and Bangladesh can be represented as follows:

$$B^1 = (p - c)[q_G(\omega^1, m^1) + q_p(\omega^1, m^1)] + G(\beta) - r(\beta)\,\beta W_B \qquad \text{For India} \quad (11)$$

$$\begin{aligned} B^2 &= (p - c)[q_G(\omega^2, m^2) + q_B(\omega^2, m^2)] - D(\beta W_B) \ \text{ if } (\beta < \hat{\beta}) \qquad \text{For Bangladesh} \\ &= (p - c)[q_G(w^2, m^2) + q_B(w^2, m^2)] - \text{ if } (\hat{\beta} < \beta < \tilde{\beta}) \\ &= (p - c)[q_G(w^2, m^2) + q_B(w^2, m^2)] - L(\beta) \ \text{ if } (\beta > \tilde{\beta}) \end{aligned}$$

In such a situation, India will have the dual opportunity to divert water in both the Ganges and Brahmaputra river basin. India's problem would be to choose the share of diversion from the Ganges River at Farakka, α_G, α_P and from the Brahmaputra River at Jogigopa, *â*, to maximize its benefit function B^1 as given in equation 11. The first order condition of the above problem can be expressed in terms of following equations:

$$(p - c)W_B \left[\left\{\frac{\partial(q_G{}^1)}{\partial(\omega_G{}^1)}\right\}(\alpha_G) + \left\{\frac{\partial(q_P{}^1)}{\partial(\omega_P{}^1)}\right\}(\alpha_P) + \right] + \frac{\partial(G)}{\partial(\beta)} - \frac{\partial(r)}{\partial(\beta)}\beta + r\ (\beta) = 0 \qquad (12)$$

$$(p - c)\left[\left\{\frac{\partial(q_G{}^1)}{\partial(\omega_G{}^1)}(W_G + \beta\ W_B)\right\}\right] = 0 \qquad (13)$$

$$(p - c)\left[\left\{\frac{\partial(q_P{}^1)}{\partial(\omega_P{}^1)}(W_G + \beta\ W_B)\right\}\right] = 0 \qquad (14)$$

Equation (12) suggests that the optimum share of water transferred from the Brahmaputra River will be chosen when the marginal benefits of increasing the share of water diverted in the downstream Ganges and peninsular river basin equals the marginal cost of the diversion of water from the Brahmaputra. Combining equations 13 and 14, we get

$$\frac{\partial(q_G{}^1)}{\partial(\omega_G{}^1)} = \frac{\partial(q_P{}^1)}{\partial(\omega_P{}^1)} \qquad (15)$$

Equation 15 suggests that India would allocate water between the Ganges and Brahmaputra so that the marginal benefit of water consumption is equal in both river basins in India. It also implies that if the waters in the peninsular basin were relatively less endowed than the availability at Farakka before the transfer, then India would divert a lesser proportion of water in the downstream Ganges Basin than in the peninsular river basin. The optimal share of water diversion from the Brahmaputra, β^* and water allocation at Farakka, $\alpha_G{}^*$, $\alpha_P{}^*$ can be determined by solving the first order conditions (12-14).

Bangladesh faces two possible regimes while maximizing its benefit function:

I. The constraint is binding $\omega^B = (1 - \beta)\ W_B$ implying that there is scarcity of water in the Brahmaputra River basin.

II. The physical water availability constraint is non binding $\omega^B \succ (1 - \beta)\ W_B$

If the water availability constraint is binding, then the optimal consumption of water of Bangladesh in the Brahmaputra River basin is $\omega^B = (1 - \beta^*)\ W_B$. In the absence of any water sharing treaty, Bangladesh's water consumption, ω^B, depends on the optimal share of water diverted by India, β, and thus is influenced by India's domestic agricultural price and usage of other inputs. A rise in agricultural production subsidies in India, for instance, will increase the demand of water there. Higher consumption of water in the upstream country will thus affect the water consumption in the Brahmaputra River basin of Bangladesh. The benefit of Bangladesh under regime I will be $B^{*2}(\alpha_G, \alpha_P, \beta)$.

In this case, Bangladesh is left with no choice variables to maximise its benefit function. Bangladesh's benefits would be dictated by India's choice of the share of water diverted from the Ganges and the Brahmaputra river, respectively. As the marginal cost of water transfer decreases with the increase in the share of water diversion, India could divert more water from the Brahmaputra to meet the water demand of the Ganges and the peninsular basins and to cover the costs of water transfer. This may lead India to divert an optimal share of water from the Brahmaputra above $\tilde{\beta}$, which may cause an environmental loss in Bangladesh.

If the water availability constraint is non binding, then Bangladesh's optimal consumption of water would be $\omega^{*}_{B}{}^{2}$. The solution represents Bangladesh's desired demand of water, which approximates the profit maximizing optimal water consumption as in the case with no water scarcity in the Brahmaputra River basin. The solution suggests that the consumptive usage of water of Bangladesh in the Brahmaputra River basin is independent of the share of water diverted by India. The benefit of Bangladesh under this regime would be $\pi^{B}(\alpha_{G}, \alpha_{P}, \omega^{*}_{B})$.

The Social Planner's Problem

In the presence of externalities, transboundary water allocation issues create a unique economic problem. In applying the definition of externality to international rivers, LeMarquand (1977) stated "An international river is a common property shared among the basin states." When water is shared by many countries, however, the problem of externalities takes a different dimension, because the river basins shared by more than one country cannot be easily planned and developed as a single unit unless all of the riparian countries agree. Only in a few cases has this been attempted, and a leading case, the Columbia River basin shared by Canada and the United States, yielded mixed results (Krutilla 1966; Roger 1993).

Several attempts have been made to develop general rules of international law to guide the sharing of water in transboundary settings (Helsinki Rules 1966; Helsinki Convention 1992; UN Convention 1996). The principles generally hinge on the notions of equality, reasonableness, and avoidance of harming one's neighbors. The fundamental goal is to achieve joint, optimum utilization of resources and avoidance of disputes over the shared water resource.

We assumed that there is a benevolent social planner who is in charge of the entire Ganges -Brahmaputra and peninsular river basin. According to the Coase Theorem (Coase 1960), the social planner will choose a water sharing allocation on the Pareto efficiency frontier – a water allocation, which is Pareto efficient. Choosing an allocation on the Pareto efficiency frontier is equivalent to maximizing the joint net benefits. The joint net benefits of the countries without altruism are represented by $Z = B^{1} + B^{2}$.

The social planner's problem would be to choose an optimal share of water transferred from the Brahmaputra River through joint maximization of the benefit functions of both India and Bangladesh with respect to the water supply constraints (1-3). In the optimization exercise, the social planner also decides about the water allocation between the Ganges and peninsular river basin by choosing the variables α_{G} and α_{P}.

The social planner’s maximization problem is:

$$\max_{\beta, \alpha_1, \alpha_2} Z = B^1 = B^2 = (p - \mathrm{c})[q^1{}_{\mathrm{G}}(\omega^!{}_{\mathrm{G}}, m^1{}_G) + q^1{}_P(\omega^!{}_{\mathrm{G}}, m^1{}_{\mathrm{G}}) + q^2{}_{\mathrm{G}}(\omega^2{}_G, m^2{}_G) + q^2{}_B(\omega^2{}_B, m^2{}_B)] + G(\beta) - r(\beta)\,\beta - D(\beta) - L(\beta) \tag{16}$$

where $D(\beta) = 0$ for $(\beta > \hat{\beta})$ and $L(\beta) = 0$ for $(\beta < \tilde{\beta})$

The first order conditions results in the following equations:

$$(p - c)W_B \left[\left\{\frac{\partial(q^1{}_G)}{\partial(\omega^1{}_G)}\right\}(\alpha_G) + \left\{\frac{\partial(q^1{}_P)}{\partial(\omega^1{}_P)}\right\}(\alpha_P) + \left\{\frac{\partial(q^2{}_G)}{\partial(\omega^2{}_G)}\right\}(1 - \alpha_G - \alpha_P) - \left\{\frac{\partial(q^2{}_B)}{\partial(\omega^2{}_B)}\right\}\right] + \left[\frac{\partial(G)}{\partial(\beta)} - \frac{\partial(D)}{\partial(\beta)}\right] = \left[\frac{\partial(r)}{\partial(\beta)}\beta + r(\beta) + \frac{\partial(L)}{\partial(\beta)}\right] \tag{17}$$

$$(p - c)(W_G + \beta W_B)\left[\left\{\frac{\partial(q^1{}_G)}{\partial(\omega^1{}_G)} - \frac{\partial(q^2{}_G)}{\partial(\omega^2{}_G)}\right\}\right] = 0 \tag{18}$$

$$(p - c)\left[\left\{\frac{\partial(q_P{}^1)}{\partial(\omega_P{}^1)}(W_G + \beta W_B)\right\} - \left\{\frac{\partial(q^2{}_G)}{\partial(\omega^2{}_P)}(W_G + \beta W_B)\right\}\right] = 0 \tag{19}$$

Equation (17) suggests that the optimum share of water transferred from the Brahmaputra River will be chosen when the marginal benefits of increasing the share of water diverted in both India and Bangladesh equals the marginal cost of the diversion of water from Brahmaputra. The first term in the left hand side of the equation indicates the weighted net marginal benefit of the countries in agricultural productivity from a unit increase in the share of water diversion from the Brahmaputra River. In the Ganges River basin, the weights are the share of each country’s augmented water flow at Farakka. The second term is an aggregate of India’s marginal gain in additional benefits and that of Bangladesh’s in flood control. The right hand side of the equation denotes the marginal cost of diverting the water from the Brahmaputra River and includes the marginal environment cost incurred by Bangladesh from an increase in the share of water diverted from Brahmaputra.

Equation 18 implies the social planner will allocate water between India and Bangladesh in the downstream Ganges River basin according to the marginal benefits of water of both countries. Equation 19 shows that at Farakka, the augmented Ganges River flow would be shared between Bangladesh in the downstream Ganges, and India in the peninsular river basins according to the marginal benefits of water.

Substituting equation 18 and 19 in equation 17, we derive the following equilibrium condition to determine the optimal shares of water allocation

$$\left[\frac{\partial(q^2{}_G)}{\partial(\omega^2{}_G)} - \frac{\partial(q^2{}_B)}{\partial(\omega_B{}^2)}\right] = \frac{\dfrac{\partial(r)}{\partial(\beta)}\beta + r(\beta) + \dfrac{\partial(L)}{\partial(\beta)} - \dfrac{\partial(G)}{\partial(\beta)} + \dfrac{\partial(D)}{\partial(\beta)}}{(p - c)\,W_B} \tag{20}$$

The above equilibrium condition suggests that the difference between the marginal benefit of water consumption of Bangladesh in the Ganges River basin and in the Brahmaputra River basin is proportional to the difference between the marginal cost and additional benefit of water transfer from the Brahmaputra River. It also implies that, if the marginal cost of water transfer is greater than the marginal additional benefits like hydropower generational and flood control, then the social planner would compensate Bangladesh by providing more water in its downstream Brahmaputra.

Finally, solving the first order conditions as given in equations 17-19, the social planner determines the optimal share of water transfer from the Brahmaputra River, β^{**}, and the share of water to the Ganges downstream α_G^{**}, and that for the peninsular river basins in India α_P^{**}.

Endogenous Risk and Environmental Losses of Bangladesh

It is imperative to assess the hypothesis whether diverting water above the threshold from the Brahmaputra River can create severe environmental damage in Bangladesh.[11] The risk of environmental damage depends on the amount of water diverted by India in upper Brahmaputra and the degree of self-protection used by Bangladesh to cover its losses. India who acts here like an emitter wants to minimize the probability of type I error, which is the probability of accepting the false null hypothesis that transferring water above the threshold will create severe environmental damage. While Bangladesh, whose role is like a receptor, in a typical environmental problem will try to minimize the probability of Type II error, which is the probability of rejecting the true null hypothesis that water diversion above the threshold level will not create severe environmental losses. Thus, for any stock of information the social planner faces a trade off between the Type I error and Type II error. As Bangladesh engages in self-protection it provides information about the linkage between the share of water transferred from Brahmaputra by India and the consequential environmental damage in India. The information will be valuable to the policymakers to assess the risk. We assume that both India and Bangladesh are risk neutral. Bangladesh is using x degree of self- protection for environmental damage, while India is supplying y proportion of water to Bangladesh in downstream Brahmaputra to control the environmental damage.

We assumed that the following restriction holds in the measure of environmental damage resistance and environmental damage control $0 < x < 1$ and $0 < y = 1 - \beta < 1$. We assumed the probability of making type I error is $P(x, y)$, while the probability of making type II error is $1 - P(x, y)$. We also presumed that:

$$P_x > 0,\ P_{xx} > 0,\ P_y > 0,\ P_{yy} > 0,\ P_{xx} P_{yy} - (P_{xy})^2 > 0 \tag{21}$$

It means that as Bangladesh reduces environmental damage through self-protection, the probability of accepting the false hypothesis (Type I error) will increase. Similarly, the probability of making type I error will increase if Bangladesh is having less damage due to the increase in the share of water diversions by India to downstream Brahmaputra. So, if environmental

---

[11] Here in this model we have used a framework developed by Crocker (1983).

damage resistance and environmental damage control are effective in reducing environmental losses, then the belief that water diversion above the threshold will create severe environment damage gets stronger. The restriction $P_{xx} P_{yy} - (P_{xy})^2 > 0$ suggests that the direct type I error effects of a change in environmental damage resistance or environmental damage control dominate the indirect effects of the change in Type II error.

Let the marginal cost of achieving a unit more of environmental damage resistance by Bangladesh be d, while the marginal cost of controlling a unit more of environmental damage by supplying more water downstream Brahmaputra be w. Both, for simplicity reasons, are assumed to be constant. So the total cost associated with the prospect of protecting the environment in Bangladesh is $dx+wy$. The additional environmental damage and control costs arising from the belief that water diversion above the threshold level will not create severe environmental loss is $L(\beta)=L(1-y)$ with the assumption $L_Y<0$. It means that as less water is flowing to the downstream Brahmaputra in Bangladesh, the environmental loss for Bangladesh will increase when further environmental protection is not adopted. The social planner's objective will be to minimize social cost with respect to the choice variable x and y. The social planner's objective function can be stated as follows:

$$\min_{x,\, y} S(x, y) = dx+wy + L(y)\,[1 - P(x,y)] \tag{22}$$

The policymaker by choosing the optimum x and y can generate information that reduces the likelihood of Type I and Type II error.

First order condition of the above problem results in the following equations

$$d = L(y)\, P_x \tag{23}$$

$$w = L_y\,[P(x, y) - 1] + L(y)\, P_y \tag{24}$$

Equation (23) suggests that at equilibrium the marginal cost of achieving a unit more of environmental damage resistance (d) by Bangladesh equals the marginal expected environmental damage for believing that that water diversion above the threshold level will not create environmental damage. Equation (24) can be interpreted by saying that the marginal cost of controlling a unit more of environmental damage (w) will be equal to marginal expected environmental damage for rejecting the true null hypothesis.

The cost minimizing solution to equation (22) is found by simultaneously solving equations (23) and (24). Thus the social planner's objective is to minimize the social cost with respect to the environmental damage resistance and environmental damage control and weigh the alternative truth standards by developing a burden sharing rule that will cause each country to generate information, which reduces the likelihood of Type I and Type II errors.

Political Economy of Water Sharing

Given countries' increasing demand for water resources, there is limited scope for cooperation to resolve such transboundary water conflicts in a social planner's way. However, we know many upstream countries do care about the downstream country to a limited extent. This is evident from the number of international agreements on water sharing that have been signed, and many of which seem to be against the own interest of upstream countries. Since 1948, about 300 water agreements have been signed and negotiated between countries (Wolf et al. 2003). In most of the cases, for instance, water sharing agreements between Egypt and Sudan in 1959; Israel and Jordan in 1994; and India and Bangladesh in 1996, the issues of water sharing were resolved without provision of side payments or compensation from downstream countries. Using a political altruism model, we make an attempt to determine the water allocation between India and Bangladesh in the situation where India might recognize the welfare of Bangladesh and enforce its water claims. In a natural extension of the standard economic model, it is possible to explain the above phenomena, by allowing for altruism between countries. We assume that India incorporates some proportion of Bangladesh's benefit function in its net benefit function. Weights are the altruistic concerns, and are based on the political relationship between the two countries. If there is a good political relationship between India and Bangladesh, then India could be altruistic toward Bangladesh and divert more water. Political relations are crucial elements influencing the altruistic behavior of the countries, and we determine the optimal allocation of water sharing based on the political relationship between the two countries. The net benefit function of India NB^1 can be expressed as

$$NB^1 = B^1 + m^1 B^B \tag{25}$$

where m^1 is the parameter reflecting India's altruism towards Bangladesh. The value of altruism factor lies between 0 and 1. If $m^1 = 1$, India would play the role of a social planner; whereas if $m^1 = 0$, then India would not care about Bangladesh and engage in maximizing its own welfare. Given the net benefit function as specified in equation 25, India would choose the optimal share of water diversion from Brahmaputra and share of water allocation between Ganges and the peninsular river basins. The first order conditions are expressed as follows:

$$(p - c)W_B \left[\left\{\frac{\partial(q^1{}_G)}{\partial(\omega^1{}_G)}\right\}(\alpha_G) + \left\{\frac{\partial(q^1{}_P)}{\partial(\omega^1{}_P)}\right\}(\alpha_P) + m^1 \left\{\frac{\partial(q^2{}_G)}{\partial(\omega^2{}_G)}\right\}(1 - \alpha_G - \alpha_P) - m^1 \left\{\frac{\partial(q^2{}_B)}{\partial(\omega^2{}_B)}\right\}\right]$$

$$- \frac{\partial(G)}{\partial(\beta)} + m^1 \frac{\partial(D)}{\partial(\beta)} = \frac{\partial(r)}{\partial(\beta)} \beta + r(\beta) + m^1 \frac{\partial(L)}{\partial(\beta)} \tag{26}$$

$$(p - c) \left[\left\{\frac{\partial(q^1{}_G)}{\partial(\omega^1{}_G)}\right\} - m^1 \left\{\frac{\partial(q^2{}_G)}{\partial(\omega^2{}_G)}\right\} \right] = 0 \tag{27}$$

$$(p - c) \left[\left\{\frac{\partial(q^1{}_P)}{\partial(\omega^1{}_P)}\right\} - m^1 \left\{\frac{\partial(q^2{}_G)}{\partial(\omega^2{}_G)}\right\} \right] = 0 \tag{28}$$

The first order conditions of the maximization problem would be similar to that of the social planner's maximization problem, but the marginal benefits of Bangladesh from water consumption would be weighted by India's altruism toward Bangladesh. Solving the first order conditions, we can derive the optimal share of water diversion from Brahmaputra, $\beta^{\pm}(m^1)$ and the water allocation at Farakka $\alpha_G{}^{\pm}(m^1)$, $\alpha_P{}^{\pm}(m^1)$. Also if $m^1 = 0$ then India would unilaterally divert water from Brahmaputra without caring about the loss of Bangladesh's welfare. The optimal share of water diversion from Brahmaputra β^* and water allocation at Farakka, $\alpha_G{}^*$, $\alpha_P{}^*$, are determined in problem 11 where India diverts water unilaterally.[12] We investigated whether India would divert less water from the Brahmaputra if the political relationship between the two countries improves.

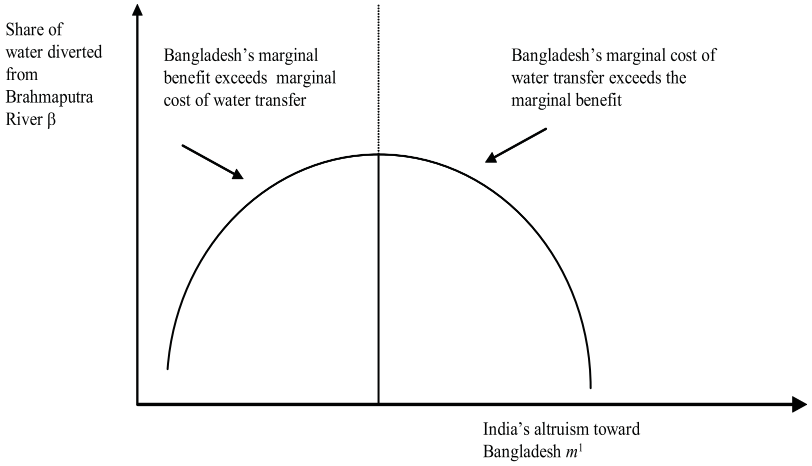
Using the implicit function theorem, we derived the effect of change in India's altruism on the share of water diversion from Brahmaputra.

$$\frac{\partial\beta}{\partial m^1} = -\frac{\frac{\partial^2 NB^1}{\partial\beta\partial m^1}}{\Delta} = -\frac{(p - c)W_B\left[\left\{\frac{\partial(q^2{}_G)}{\partial(\omega^2{}_G)}\right\}(1 - \alpha_G - \alpha_P) - \left\{\frac{\partial(q^2{}_B)}{\partial(\omega^2{}_B)}\right\}\right] - \frac{\partial(D)}{\partial\beta} - \frac{\partial(L)}{\partial(\beta)}}{\Delta} \qquad (29)$$

$$\text{where } \Delta = \begin{bmatrix} \frac{\partial^2 NB^1}{\partial\beta^2} & \frac{\partial^2 NB^1}{\partial\beta\partial\alpha_G} & \frac{\partial^2 NB^1}{\partial\beta\partial\alpha_{P2}} \\ \frac{\partial^2 NB^1}{\partial\alpha_G\partial\beta} & \frac{\partial^2 NB^1}{\partial\alpha_G{}^2} & \frac{\partial^2 NB^1}{\partial\alpha_G\partial\alpha_P} \\ \frac{\partial^2 NB^1}{\partial\alpha_P\partial\beta} & \frac{\partial^2 NB^1}{\partial\alpha_G\partial\alpha_P} & \frac{\partial^2 NB^1}{\partial\alpha_P{}^2} \end{bmatrix} < 0$$

The matrix in the denominator of the right hand of equation 29 represents the second order condition of the maximization net benefit of India, which is negative. The numerator of the equation is the difference between Bangladesh's marginal benefit and the marginal cost of water diversion by India. If Bangladesh's marginal benefit of water diversion from Brahmaputra exceeds the marginal cost, then India will divert more water from Brahmaputra with the increase in level of altruism. On the other hand, if the marginal cost exceeds the marginal benefit, then India would divert less water with the increase in altruism. So we get a concave relationship between India's share of water diversion and the latter country's altruism towards Bangladesh.[13] The relationship is illustrated in Figure 4.

Figure 4. Relationship between share of water diversion from Brahmaputra and India's altruism.



---

[12] Similar results can be obtained by setting $m^1 = 0$ in the first order conditions (26-28).

[13] The concave relationship between Bangladesh and India's share of water diversion, and the latter country's altruism towards the former holds only for concave benefit function of Bangladesh.

Why Bangladesh Could Reject India's Proposal?

If India is sufficiently altruistic then she could divert a share of water, which could make both countries better off. However, in the future, changes in political relationship between the two countries can worsen the degree of altruism that India offers to Bangladesh. If there is a hostile relationship between India and Bangladesh in the future, India could choose to unilaterally divert water from Brahmaputra, and make Bangladesh worse off in terms of its net benefit. In the model, we assume that India would not care about Bangladesh with a probability ρ. Given this uncertainly in political relationships, Bangladesh fears of loss in net benefits largely due to environmental losses in the Brahmaputra River basin. India may also unilaterally divert more water at Farakka and allow less water in the downstream Ganges in Bangladesh. Due to the risk of unilateral diversion of water from the river by India, Bangladesh may reject India's proposal of river linking.

If Bangladesh rejects India's proposal, it's expected benefit would be $E(B^2) = \rho B^2 (\alpha^1_0, \omega^{*2}_B) + (1\text{-}\rho)B^2 (\alpha(m^1), \omega^{*2}_B)$ where α^1_0 is the share of water diverted by India unilaterally at Farakka, and $\alpha(m^1)$ is the share of water diverted by India given the political relationship. As India would divert less water in the upstream in the case where it cares about Bangladesh we have $\alpha(m) < \alpha^1_0$. Similarly, if Bangladesh accepts India's proposal of river linking, the expected benefit of Bangladesh can be represented as:

$E(B^2) = pB^2(\alpha^*_G, \alpha^*_P\ \beta^*) + (1\text{-}\rho)B^2 (\alpha^\pm_G, \alpha^\pm_P, \beta^\pm, m^1)$ where Bangladesh benefit

$B^2(\alpha^*_G, \alpha^*_P\ \beta^*)$ from water transfer is lower in the case of hostile political relationship than the benefit in the case $B^2 (\alpha^\pm_G, \alpha^\pm_P, \beta^\pm, m^1)$ where India cares about its welfare.

Assuming Bangladesh is risk neutral, then she may accept India's proposal if

$$\rho[B^2(\beta^*, \alpha^*_G, \alpha^*_P) - B^2 (\alpha^1_0, \omega^{*2}_B)] + (1\text{-}\rho)[B^2 (\alpha^\pm_G, \alpha^\pm_P, \beta^\pm, m^1) - B^2 (\alpha(m^1), \omega^{*2}_B)] > 0$$

The above expression can be simplified to:

$$\rho < \frac{[B^2 (\alpha^\pm_G, \alpha^\pm_P, \beta^\pm, m^1) - B^2 (\alpha(m^1), \omega^{*2}_B)]}{[B^2 (\alpha^\pm_G, \alpha^\pm_P, \beta^\pm, m^1) - B^2 (\alpha^*_G, \alpha^*_P, \beta^*)] - [B^2 (\alpha(m^1), \omega^{*2}_B) - B^2 (\alpha^1_0, \omega^{*2}_B)]} \tag{30}$$

The above inequality suggests that Bangladesh will accept India's proposal, if the probability of the hostile relationship is less than the ratio of Bangladesh's net benefit from water transfer under altruism to that of change in net benefit from altruism under water transfer.

In order to build the link between the two rivers, it is necessary for India to make Bangladesh agree to the proposal given in the existing international law of transboundary water sharing. Creating new sources to augment water supply requires large investments and effective institutions for allocating water. Implementation of these measures requires cooperation and coordination between regions.

India is optimistic about Bangladesh agreeing to the river linking proposal. We denote the probability that Bangladesh would accept India's proposal as υ. We assume that the probability, υ is endogenous and depends on the expected political relationship between India and Bangladesh, and can be expressed as $\upsilon = \upsilon(E(m^1))$. As the probability is endogenous, India can take the opportunity to induce Bangladesh to accept the proposal of water transfer from Brahmaputra through insuring the loss in the latter country's benefit in the case of political uncertainty. Suppose India is willing to pay a proportional of premium to θ an international insurance firm to protect against the risk of Bangladesh's loss of benefit due to future political uncertainties. The proportion of risk premium, a, India would pay lies between 0 and 1.The insurance firm would also insure that in case of environmental and economic loss due to excess water diversion, Bangladesh would get back a proportion of loss in net benefits, Ω where $\Omega = B^2 (\alpha^{\pm}_{G}, \alpha^{\pm}_{P}, \beta^{\pm}, m^1) - B^2 (\alpha^{*}_{G}, \alpha^{*}_{P}, \beta^{*})$. In such a case Bangladesh's probability of accepting India's proposal would be greater with insurance and $\upsilon = \upsilon(E(m_1)) < \upsilon(E(m_1, a))$.

In the framework of a simple insurance model, we examine the equilibrium outcome in terms of the insurance premium that India would like to pay to maximize Bangladesh's chance of agreeing to the proposal, and thereby maximizing India's net benefit over an infinite period of time.

India's problem is to choose the value of the insurance premium a so that it maximizes the following expected net benefit function of India.

$$H=(1-\upsilon(a, E(m))[NB^1(\alpha(m^1)]+\upsilon(a, E(m)\left\{\begin{array}{l}[NB^1(\beta^{\pm}, \alpha^{\pm}_{G}, \alpha^{\pm}_{P}, m^1)-a\theta)] \\ +\delta[\rho[(NB^1(\beta^{*}, \alpha^{*}_{G}, \alpha^{*}_{P})]+(1-\rho)[NB^1(\beta^{\pm}, \alpha^{\pm}_{G}, \alpha^{\pm}_{P}, m^1)-a\theta]] \\ +\delta^2[\rho[(NB^1(\beta^{*}, \alpha^{*}_{G}, \alpha^{*}_{P})]+(1-\rho)[NB^1(\beta^{\pm}, \alpha^{\pm}_{G}, \alpha^{\pm}_{P}, m^1)-a\theta]]\end{array}\right\}$$

where δ is the discount rate.

Simplifying the above expression we get,

$$H=(1-\upsilon(a, E(m)[NB^1(\alpha(m^1)]+\upsilon(a, E(m)\left\{NB^1(\beta^{\pm}, \alpha^{\pm}_{G}, \alpha^{\pm}_{P}, m^1)-a\theta)] \frac{1-\delta\rho}{1-\delta} +[(NB^1(\beta^{*} \alpha^{*}_{G}, \alpha^{*}_{P})]\frac{\delta\rho}{1-\delta}\right\} \quad (31)$$

The first order condition can be represented as

$$\frac{\partial(H)}{\partial(a)} = - \frac{\partial\upsilon(a, E(m^1))}{\partial a}[NB^1(\alpha^{*})]+ \frac{\partial\upsilon(a, E(m^1))}{\partial a} [[NB^1(\beta^{\pm}, \alpha^{\pm}_{G}, \alpha^{\pm}_{P}, m^1)-a\theta)] \frac{1-\delta\rho}{1-\delta} \quad (32)$$
$$+[(NB^1(\beta^{*}(\alpha^{*}_{G}, \alpha^{*}_{P})]\frac{\delta\rho}{1-\delta})]+ \frac{\upsilon(a, E(m)}{1-\delta}[-\theta (1-\delta\rho)] = 0$$

where, $m^1 > 0$, $0 < a < 1$.

Solving the first order condition, India would determine optimal premium for the loss in net benefits due to political uncertainty. The first order condition suggests that India would choose to pay a proportion of the premium so that its marginal cost of influencing the probability of Bangladesh accepting the treaty is equal to the marginal benefit acquired from water transfer. However, India will not insure Bangladesh's loss if doing so is not expected to increase the net benefits of India. Thus although the overall gain to India from such a water augmentation might be reduced from paying such insurance, India would still benefit compared to the current situation without any water transfers from Brahmaputra. With both countries gaining, it is possible that they might negotiate successfully an international water transfer treaty with a provision of hedging the risk of political uncertainty using suitable insurance mechanism for environment loss.

Simulation Results

In the past, limited analysis of water allocation of the optimal allocation of the Ganges and the Brahmaputra River basin based on actual data sets was conducted due to lack of data regarding water flow in the respective river basins.

As an alternative approach, we have used simulations to predict the outcomes of the theoretical model using the Latin Hypercube technique.[14] Using simulations, we attempt to determine the optimal allocation of the share of water by a social planner, and also in the case where India has the opportunity to divert water given the political relationship between the two countries.[15] The optimal water allocation has been computed by simulation using computer software 'RISK Optimizer'.[16]

We seek to illustrate how political relationship factors might have influenced the share of water diversion from Brahmaputra and the water allocation between India and Bangladesh.

In the simulation, we have assumed that the total flow of water in each river basin is subject to stochastic variability. The uncertainty in the flow of water can be attributed to environmental changes in the headwaters of the rivers such as deforestation and dwindling glaciers as a result of climate variability and change. As an example of stochastic dependence in the flow of water, low rainfall or a hot summer may simultaneously lower W and raise the marginal benefit of water for both the countries, thus, the flow of water, $W_{t\,i}$, at time period t in jth river basin $(j=G\ ,B)$ can be represented by

$$W_{t\,i} = \overline{W} + \varepsilon_{t\,j}, \tag{33}$$

where $\overline{W}_i$ is the long run average flow of water of at the point of diversion and ε_{jt} is the stochastic variable factor.

Simulation results in the model suggest that the stochastic factor, ε_{jt}, is best fitted with a lognormal distribution with zero mean and a known constant variance σ.[17] The variance of the distribution function of the uncertain element in the water flow provides a degree of information or knowledge about the flow of water in a given time period. We assume that both India and Bangladesh has the opportunity to access accurate water flow information, and know the true variance of the stochastic disturbance of the flow of water. The water allocation decision between the two countries depends on the uncertainty in the flow of water and, hence it is based on the degree of information about the flow of water.

---

[14] Latin Hypercube sampling (Iman et al.1980) has been shown to require fewer model iterations to approximate the desired variable distribution than the simple Monte Carlo method. The Latin Hypercube technique ensures that the entire range of each variable is sampled. A statistical summary of the model results will produce indices of sensitivity and uncertainty that relate the effects of heterogeneity of input variables to model predictions.

[15] There is a caveat .Much of the benefit and cost functions are not fully based on empirical data and the outcome of the simulation may change substantially.

[16] RISKOptimizer is the simulation optimization add-in for Microsoft Excel®. It allows the optimization of Excel spreadsheet models that contain uncertain values. RISKOptimizer runs an optimization of simulations, finding the combination of adjustable cells that provides the best simulation results.

[17] Using Best Fit Software and empirical data, we determined the distribution function of the water flow of the Ganges.

We also assume that in the case where India diverts water from Brahmaputra and Farakka based on political relationship, the country's altruistic concerns for Bangladesh is also subject to uncertainty and follows a uniform and discrete distribution.

We make the problem more tractable by assuming a specific form of benefit functions of both countries. The specific benefit functions of India and Bangladesh are presented in Table 1. And the simulations results are shown in Table 2.

Table 1. Assumptions in the simulation.

Parameters and Variables	Computation and Values	Explanation
India's political relationship with Bangladesh, m^1	$[0.1\ 0.9]$,$0<m^I<1$	India cares more about itself than Bangladesh. m^1 follows uniform discrete distribution
Water flow of the Ganges at Farakka	$W^1_G = \overline{W}^1_G + \varepsilon_G$ where ε_G follows lognormal (0, σ) $\overline{W}^1_G$ = 69 billion cubic meters(long-term average flow of water) $\sigma = 12$.	Derived from existing empirical data (Biswas 2001); used best fit software to derive the distribution
Water availability of Brahmaputra at Jogighopa	$W^1_B = \overline{W}^1_B + \varepsilon_B$ where ε_B follows lognormal (0, σ) $\overline{W}^1_B$ = 537 billion cubic meters(long-term average flow of water) $\sigma = 98$.	Derived from existing empirical data (Crow 1995); used best fit software to derive the distribution
Water withdrawal in Cauvery and pennar river basin under current situation.	ω^1_P = 32 billion cubic meters	Derived from existing empirical data (Amarasinghe et al. 2005); used best fit software to derive the distribution
Agricultural benefit function of India (π^1_G) in Ganges River basin	$\pi^1_G = .04(\omega)^{1/2}$	The form of India's benefit function is based on the concavity assumption The quadratic benefit function is assumed for computational simplicity. Also we have taken into account each country's marginal productivity of water in each basin from Nasima (Chowdhury 2005)
Agricultural benefit function of India (π^1_G) in Cauvery and Pennar River basins	$\pi^1_G = .03(\omega)^{1/2}$	
Agricultural benefit function of Bangladesh (π^1_G) in Brahmaputra	$\pi^1_G = .02(\omega)^{1/2}$	
Agricultural benefit function of Bangladesh (π^1_G) in Ganges River basin	$\pi^1_G = .03(\omega)^{1/2}$	
Flood control damage function $D(\beta)$ in Brahmaputra River basin	$D = 0.4\ ([1-\beta)\ W_B]^{1/3} = 0$ for $\beta > .10$	The form of Bangladesh's flood damage and environmental loss function and India's marginal cost of transfer water is based on the assumption and literature review
Environmental loss function $L(\beta)$ in Brahmaputra River basin	$L = 0.3\ [\beta W]^{1/3}$ $= 0$ for $\beta < k$ $k = [0.15, 0.25]$	
Marginal cost or water transfer	$r = 0.003\ (\beta W_B)^{-1/3}$	
Share of water α according to Ganges Treaty	$\alpha = 0.5$	

Table 2. Simulation results.

Decision Unit	Share of water diversion in percentage			Threshold level of environmental damage $\tilde{\beta}$	Expected change in present total benefit from water transfer(percentage) per year	
	Ganges (India) α_G	Peninsular (India) α_P	Brahmaputra β		India	Bangladesh
Social	40	23	12	>15	43.61	41.01
Planner	39	22	10	10	42.31	42.9
India with average altruism	41	24	14	>15	58.65	29.59
	43	25	10	10	48.87	27.19
India without altruism	40	36	22	>10	93.98	-102.07

Source: Authors' estimates

The simulation results suggest that in the case where the social planner decides about water allocation, the optimal share of water diverted from Brahmaputra could be between 10 to 12 % of the total availability of water of the Brahmaputra River at Jogighopa, and is below the threshold level of environmental damage of Bangladesh. The expected change in present discounted benefit from water transfer would be nearly the same for both countries.

In the case where India cares about Bangladesh with average altruism, India's expected benefit would increase more. But, India would still forgo substantial benefits to Bangladesh when the transfers are taking place under political altruism than the case where India has the opportunity to unilaterally divert water. However, India would forgo less if the threshold level of environmental damage is above 15 % of the total flow of Brahmaputra River.

The share of water allocation of the augmented water at Farakka for India would range from 61 % in the case of water allocation by a social planner to 76 % in the case where India has an opportunity to unilaterally divert water.

Bangladesh could incur a loss of up to 177 % if India diverts water unilaterally under a hostile political relationship. The expected change in benefits of Bangladesh would decline if India decides the water share based on a political relationship. Uncertainty in political relationships between India and Bangladesh could induce India to divert water unilaterally; and it could be one of the reasons for Bangladesh to reject India's proposal to transfer water from Brahmaputra, even though Bangladesh could be better off from a water transfer under a cooperative situation.

Conclusion

In this paper we have attempted to analyze the effects of inter-linkage of the Ganges and Brahmaputra River basin on future water allocation between India and Bangladesh. From a social planner's perspective, we determined the optimal diversions of water from Brahmaputra. We also examined the endogeniety of risk of environmental losses in Bangladesh if India diverts a share of water above the threshold level from Brahmaputra River. Bangladesh can use self-protection as a means of resistance to environmental damage, while India can supply more water to downstream Brahmaputra River as a control measure to environmental damage. The social planner's objective will be to minimize social cost with respect to the environmental damage resistance and environmental damage control.

Assuming the structural forms of the benefit functions of both countries, we simulated the optimal allocation of water sharing and the associated expected change in benefits of the countries from water transfer. Results suggested that both countries could be better off if water is allocated according to the social planner's decision rule. Bangladesh would enjoy a substantial benefit from reduced flood damage in the Brahmaputra Basin and the augmented water flow in the downstream Ganges.

We also explored the situation where India cares about the welfare of Bangladesh. Using a political altruistic model, we determine the water allocation between India and Bangladesh. In the model we assume that if there is a good political relationship between India and Bangladesh, then India could be altruistic towards Bangladesh and divert more water in the downstream.

However, we recognize the risk in benefit loss of Bangladesh that could stem from the hostile political relationship between the two countries. In such case of political uncertainty, India has the opportunity to divert water unilaterally and Bangladesh could incur huge environmental damage that would outweigh its benefits from water transfer. We have derived the conditions under which Bangladesh could reject such an Indian proposal of river linking.

Given the international laws on water sharing, it is essential for India to make Bangladesh agree to such a proposal. We examined the conditions determining whether Bangladesh would accept such a supplemental water augmentation treaty, and also whether such an agreement can guarantee a potential Pareto improvement.

To induce Bangladesh to agree to such proposals, India may promise to insure some proportion of Bangladesh's environmental and agricultural loss if a hostile political situation induces India to divert water unilaterally in the future. Thus, although the overall gain to India from such a water augmentation might be reduced from paying such insurance, India would still benefit compared to the current situation without any water transfers from Brahmaputra. With both countries gaining, it is possible that they might negotiate successfully an international water transfer treaty with a provision of hedging the risk of political uncertainty using suitable mechanisms, without resorting to a less satisfactory 'victims pay' outcome (Bennett et al. 1998).[18]

---

[18] Bennett et al. (1998) point out that water diversion by the upstream country imposes unidirectional external costs on the downstream country, which leads to an unsatisfactory 'victims pay' outcome under a traditional game theory approach whereby the downstream country may need to bribe the upstream country to prevent such diversion from occurring.

References

Ahmed, M.; Roy, K. 2006. Utilization and Conservation of Water Resources in Bangladesh. Paper presented at TUSUKUBA Asian Seminar on Agricultural Education (TASAE), Bangladesh, 7-14 November.

Alexander, C.; Dabelko, G. D.; Wolf, A. T. 2004. Water, Conflict, and Cooperation. Policy Briefing Paper, United Nations Foundation, Washington, D.C.

Amarasinghe, U.A; Sharma, B. R.; Aloysius, N.; Scott, C.; Smakhtin, V.; Fraiture, C.D.; Sinha, A.K.; Shukla, A.K. 2005. *Spatial variation in water supply and demand across river basins of India.* Research Report 83, Colombo, Sri Lanka: International Water Management Institute.

Beach, H. L.; Hamner, J. ; Hewitt, J.; Kaufman, E.; Kurki, A.; Oppeneimer, J. A.; Wolf, A.T. 2000. Transboundary Freshwater Dispute Resolution: Theory, Practice and Annotated Reference. New York. United Nations University Press.

Bennett, L L.; Ragland, S. E.; Yolles, P. 1998. Facilitating International Agreements Through an Interconnected Game Approach: The Case of River Basins, in Conflict and Cooperation on Transboundary Water Resources, edited by Richard E. Just and Sinaia Netanyahu. Boston, USA: Kluwer Academic Publishers. pp 61-85.

Biswas, A. K.; Uitto, J. I. 2001. Management of International Rivers. In *Sustainable Development of the Ganges–Brahmaputra–Meghna Basins*, eds. Asit K. Biswas and Juha I. Uitto. New York: United Nations University Press.

Cai, X.; McKinney, D. C.; Lasdon, L.2001. Solving Nonlinear Water Management Models Using a Combined Genetic Algorithm and Linear Programming Approach. *Advances in Water Resources 24*(6): 667–676.

Chowdhury, N T. 2005. The Economic Value of Water in the Ganges Brahmaputra –Meghna (GBM) River Basin. Goterborg, Sweden: Goteborg University,

Coase, R. H. 1960. The Problem of Social Cost. *Journal of Law & Eco*nomics. 3, p. 1

Crocker, T. 1983. Scientific Truths and Policy truths in Acid Deposition Research. *Acid Precipitation Series*-Vol-8.

Crow, B. Alan, L.; Wilson, D. 1995. “Sharing the Ganges.” Dhaka, Bangladesh: University Press Ltd,

Crow, B.; Singh, N. 2000. Impediments and Innovation in International Rivers: The Waters of South Asia. *World Development* 28 (11):1907-1925.

Dinar, A.; Wolf, A. T. 1994. International Markets for Water and the Potential for Regional Cooperation: Economic and Political Perspectives in the Western Middle East. *Economic Development and Cultural Change* 43 (1): 43-66.

Dinar, S.; Dinar, A. 2000. Negotiating in International Watercourses: Diplomacy, Conflict and Cooperation. *International Negotiation* 5:193-200.

Government of India, Ministry of Water Resources .1999. *Integrated Water Resource Development – A Plan for Action*. Report of the National Commission for Integrated Water Resources Development, Vol. - I. New Delhi, India.

Helsinki Convention. 1992. “UN Economic Commission for Europe (UN-ECE) Convention on the Protection and Use of Transboundary Watercourses and International Lakes.” *United National Economic Commission for Europe*.

Helsinki Rules .1966. The Helsinki Rules on the Uses of the Waters of International Rivers, *International Law Association.*

Hossain, I. 1998. Bangladesh-India Relationship: The Ganges Water–Sharing Treaty and Beyond. *An American Review* 25 (3):131-151.

Howe, C W.; Schurmeier, D. R.; Shaw, W. D .1986. Innovative Approaches to Water Allocation: The Potential for Water Markets. *Water Resource Research* 22 (4):439-448.

Huda, A.; Shamsul, T.M. 2001. Constraints and Opportunities for Cooperation towards Development of Water Resources in the Ganges Basin. In *Sustainable Development of the Ganges–Brahmaputra–Meghna Basins*, eds. Asit K. Biswas and Juha I. Uitto. New York, USA: United Nations University Press. pp. 46-57.

Iman, R. L.; Davenport, J. M.; Zeigler, D. K. 1980. “Latin Hypercube Sampling (Program User’s Guide).” *Technical Report SAND* 79-1473, Sandia National Laboratories, Albuquerque, NM.

Iyer, R. R. 2003. *Water Perspectives, Issues and Concerns.* New Delhi, India: Sage Publication.

Just, R E.; Netanyahu, S.1998. “*International Water Resource Conflicts: Experience and Potential, in Conflict and Cooperation on Transboundary Water Resources,*” eds. Richard E. Just and Sinaia Netanyahu. Boston, USA: Kluwer Academic Publishers, pp 1-26.

Khan, T. A. 1996. Management and Sharing of the Ganges. *Natural Resources Journal* 36 (3):455-479.

Kilgour, D. M.; Dinar, A. 2001. Flexible Water Sharing within an International River Basin. *Environmental and Resource Economics* 18 (1):43-60.

Krutilla, V. J. 1966. *The Columbia River Treaty*. Baltimore, USA: John Hopkins Press.

LeMarquand, G. D. 1977. *International rivers: The politics of cooperation.* Working Paper University of British Columbia and the Waterloo Research Centre.

Ninno, D. C.; Dorosh, P.A.; Smith, L.C.; Roy. D.K. 2001. *The 1998 floods in Bangladesh disaster impacts, household coping strategies, and response*. Research Report 122. Washington, D.C., USA: International Food Policy Research Institute.

Nishat, A.; Faisal, I.M. 2000. An Assessment of the Institutional Mechanisms for Water Negotiations in the Ganges-Brahmaputra-Meghna System. *International Negotiation* 5: 289-310.

Rogers, P. 1993. “The Value of Cooperation in Resolving International River Basin Disputes.” Natural Resources Forum Vol. 17, No. 2, pp. 117-131, May 1993.

Shah, R.B. 2001. Ganges-Brahmaputra: The Outlook for the Twenty-First Century.” In *Sustainable Development of the Ganges–Brahmaputra–Meghna Basins*, eds. Asit K. Biswas and Juha I. Uitto. New York, USA: United Nations University Press. pp 17-45.

Sultana, R. 2005. “India’s Ambitious River-linking Plan Irks Bangladesh.” *Asia Water Wire*, November 2005.

Thakkar, H. 2007. “Interlinking of Rivers in India: Dimensions of Social Impacts.” *South Asia Network on Dams, Rivers & People*. pp 1-16.

UN Convention. 1997. “United Nations Convention on the Law of the Non-navigational Uses of International Watercourses.” *UN General Assembly in Resolution 51/229.*

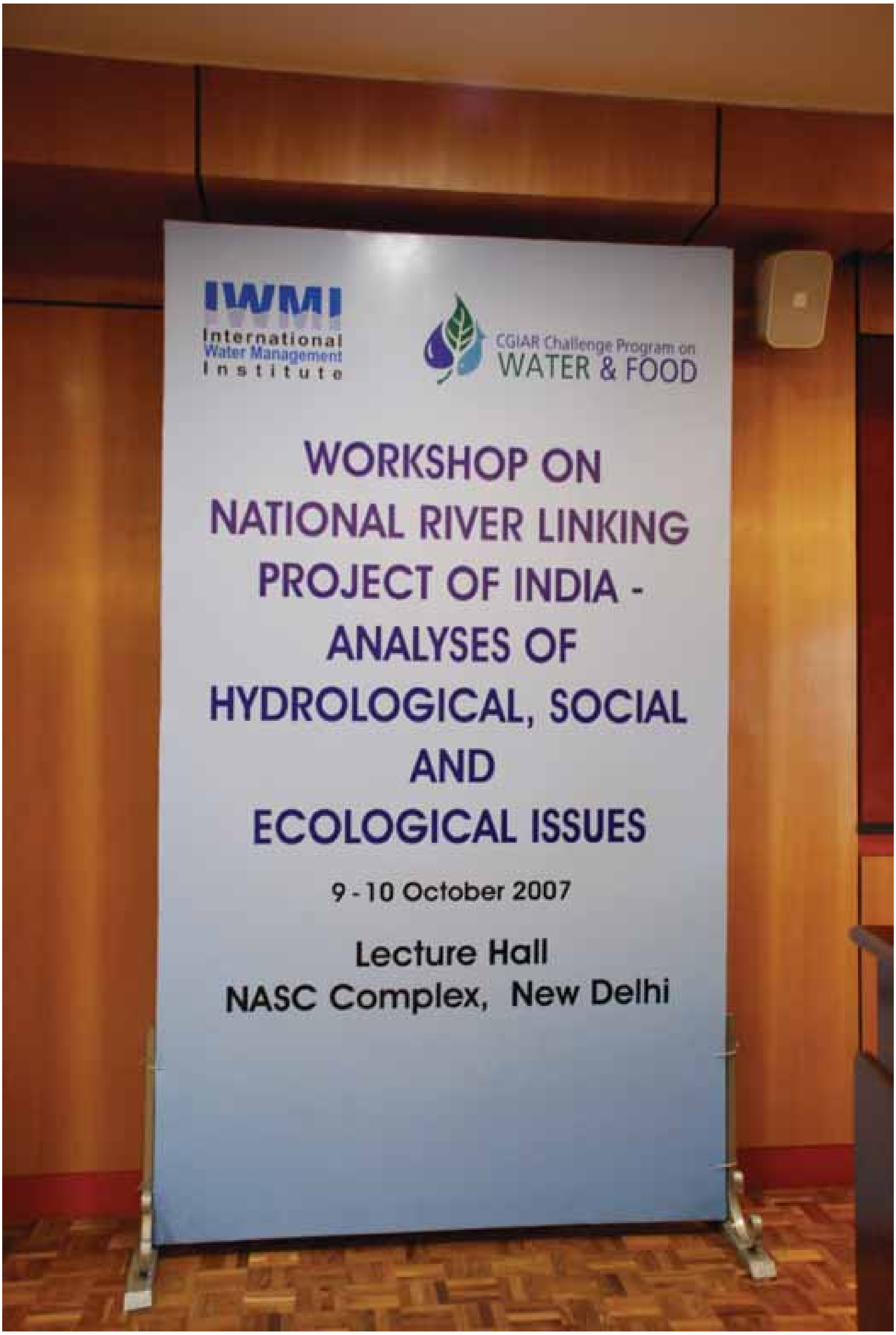
Varghese, B.G. 1997. Water Conflicts in South Asia. *Studies in Conflict & Terrorism* 20:185-194.

Wolf, A T. 2001. Water, Conflict, and Cooperation 2020 *Focus*, October 9, 2001.

Wolfe, A T.; Yoffe, S. B.; Giordano, M .2003. International Waters: Identifying Basins at Risk. *Water Policy* 5 (2003) 29–60.

Wolf, A.; Krammer, A.; Carius. A.; Dabelko, G. D. 2005. Managing Water Conflict and Cooperation. *State of the World: Redefining Global Security.* The Worldwatch Institute. pp.80-95.

Annexes


IWMI
International
Water Management
Institute
CGIAR Challenge Program on
WATER & FOOD
WORKSHOP ON
NATIONAL RIVER LINKING
PROJECT OF INDIA -
ANALYSES OF
HYDROLOGICAL, SOCIAL
AND
ECOLOGICAL ISSUES
9 - 10 October 2007
Lecture Hall
NASC Complex, New Delhi

Dr. Madar Samad, Head IWMI South Asia, welcoming the participants.

Prof. M.S. Swaminathan, the Chairman of the Advisory Committee, delivering the key-note speech.

Mr. Suresh Prabhu, former chairman of the government task force for the River Linking Project, giving a special invitee address.

Dr. Tushaar Shah, Principal Researcher, IWMI, explaining what is encompassed in the IWMI-CPWF project 'Strategic Analysis of National River Linking Project of India'.

Dr. Tushaar Shah, making a strong point!

Dr. Peter G. McCornick, Dircetor, IWMI Asia Region, responding to questions.

Section of the participants.

Section of the participants.

Section of the participants.

Section of the participants.

Section of the participants.

Section of the participants.

Section of the participants.

Section of the participants.

Presentation 1

National River Linking Project and Perspectives on Indian Irrigation

Perspectives from Track II Research

Tushaar Shah
Principal Researcher, IWMI, Anand, India

NRLP – Phase II

- Original Proposal

– Conduct a detailed SCBA of NRLP

– But, data scarcity is a major constraint

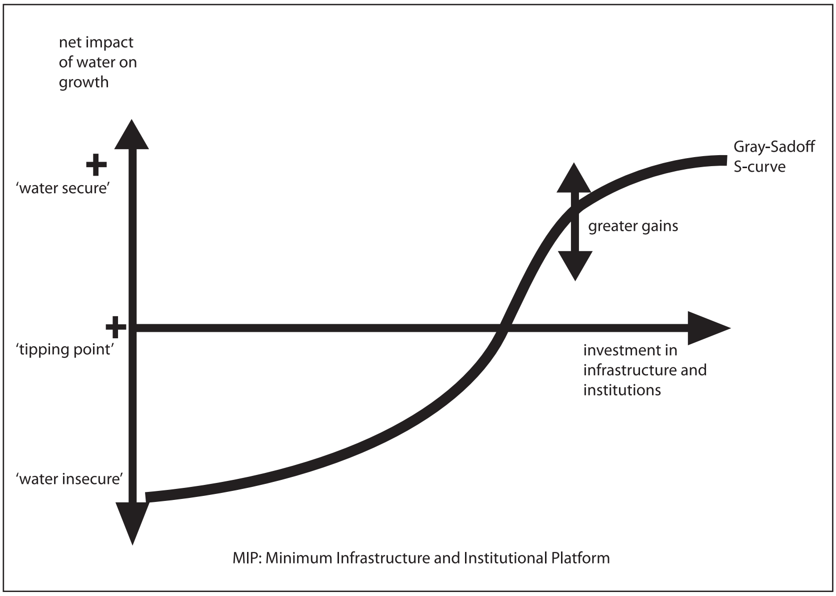
- Revised Plan – Track II Objectives

– Make a realistic assessment of past investments in public irrigation vis-à-vis IRR, food production, livelihoods, poverty;

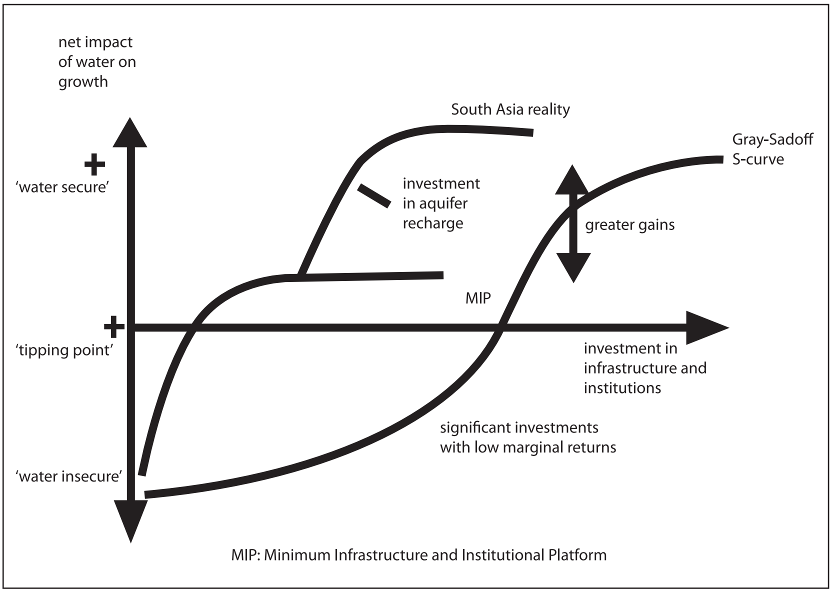
– Assess present state of Indian irrigation;

– Assess whether NRLP as an idea/concept that makes overall socioeconomic, environmental and political sense.

The dominant view about the relationship between public irrigation investments, and water security: The Gray-Sadoff Model



Reality of Indian Irrigation Circa 2000

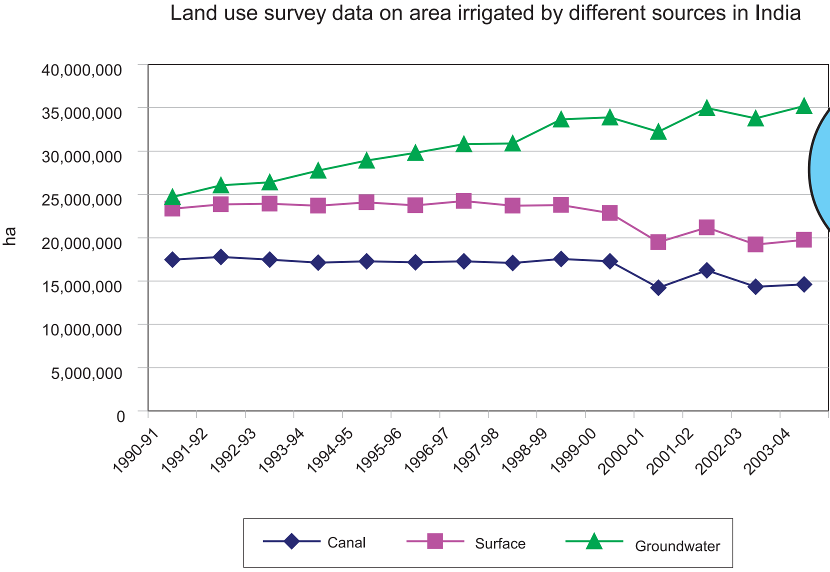


Canal commands and tank *ayacuts* are shrinking throughout South Asia

	Net irrigated area under surface irrigation (000'ha)			Net irrigated area served by groundwater (000' ha)		
	1993-4	2000-1	% change	1993-4	2000-1	% change
Key Indian states	15,633	11,035	-29.4	17,413	21,760	+25
Pakistan Punjab	4,240	3,740	-11.8	8,760	10,340	+18
Sindh	2,300	1,960	-14.8	140	200	+42.9
Bangladesh	537	480	-10.7	2,124	3,462	+63
All areas	22,709	17,215	-24.2	28,437	35,762	+25.8

Note. India and Pakistan lost 5.5 m ha of canal irrigated areas during 1993-4 to 2000-1

Rs.100,000 crores spent since 1991, but no additional benefits. There has been no addition to Canal Irrigated areas for 14 years

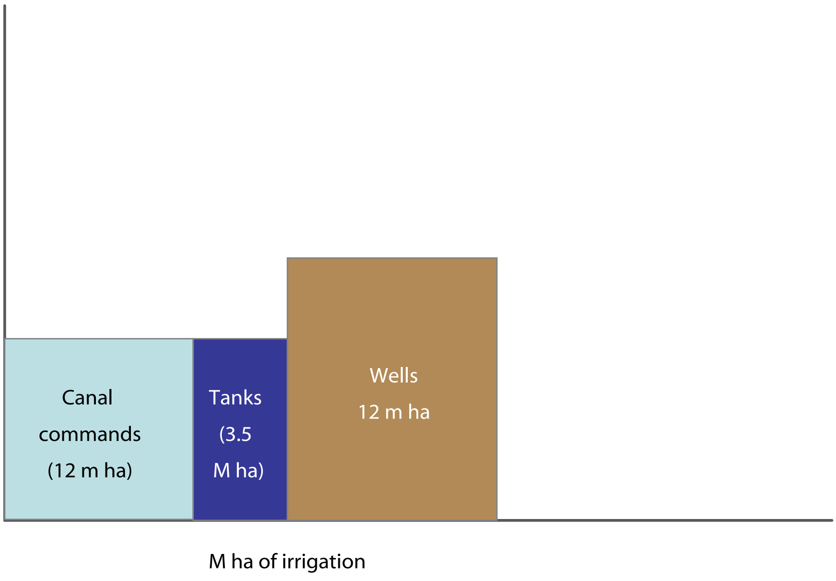


What purpose might SCBA serve when investments fail to add to irrigation?

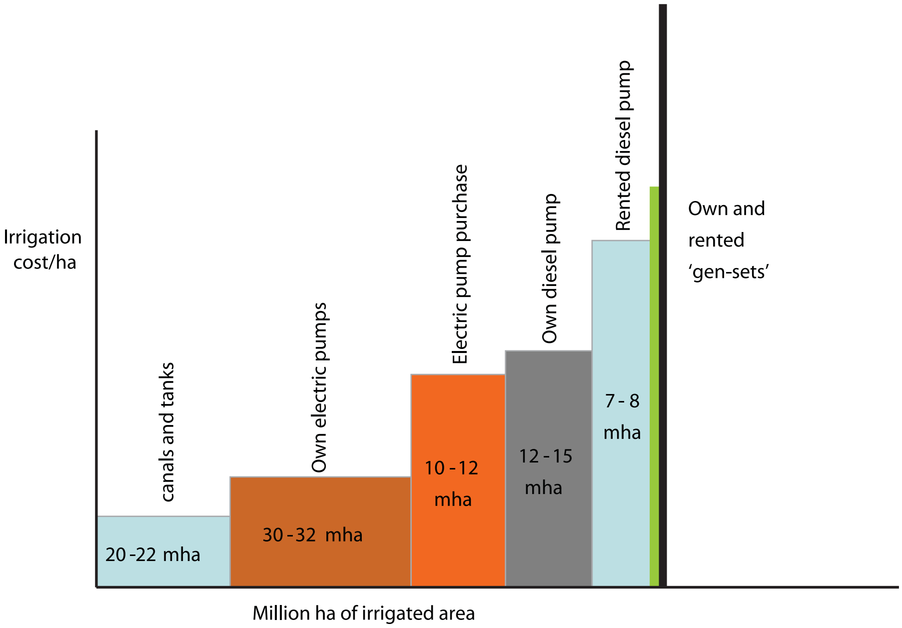
Sources: 1. CWC annual year books, various years
2. Ministry of Agriculture, agricultural statistics, various years
3. Website of Ministry of Agriculture, Government of India, http://agricoop.nic.in/Agristatistics.htm

Indian Irrigation c 1970

- Irrigation cost (Rs/ha)



Classes of Irrigators in India-c2000



Key Ideas and Conclusions from Track II Research

- Post-1991, canal irrigated area has stopped responding to public investments; 99,000 crore invested has added nothing to command areas;
- The way India plans irrigation is divorced from the way Indian irrigation actually functions. The challenge of irrigation management lies in the groundwater economy;
- Declining areas under gravity flow irrigation indicate a fundamental shift in the patterns of agricultural water use in South Asia;
- Investments in large irrigation systems are questioned on environmental and social grounds—but now questions are arising on whether they generate any irrigation benefits at all;
- The real agricultural water management issues are around the energy-irrigation nexus; and little is being done on these.

Presentation 2

Future Global Water Challenges:

Insights from the Comprehensive Assessment

Peter G. McCornick, Director, Asia
International Water Management Institute, Colombo, Sri Lanka.

COMPREHENSIVE
Assessment
of water management
in agriculture

Co-Sponsors

CGIAR

Ramsar

FAO
FIAT PANIS

CBD

- Critically evaluated past developments, challenges faced and solutions developed
- Enable better informed investment and management decisions in water and agriculture
- Broad multi-institutional partnership of more than 700 practitioners, researchers and policymakers

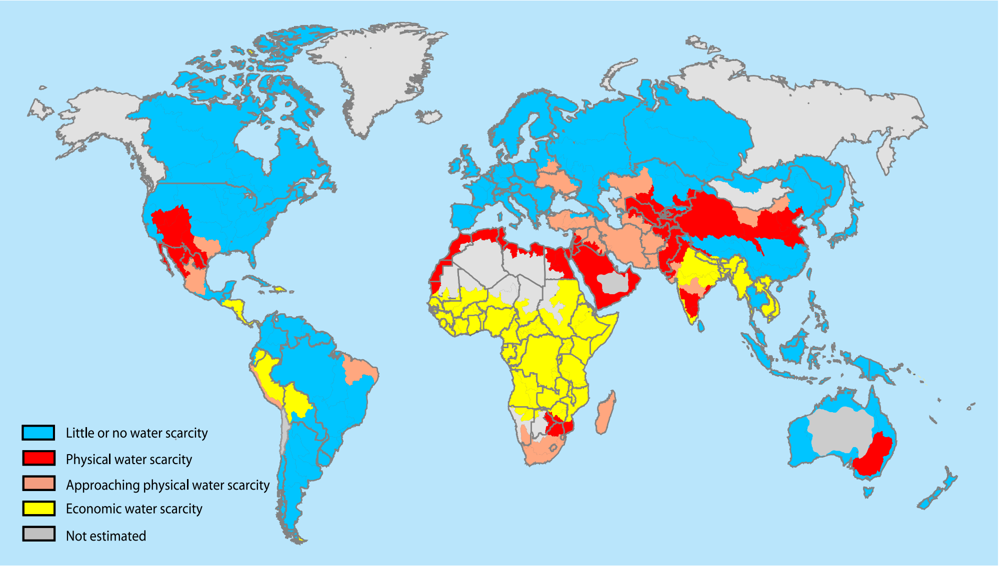
Main Assessment Book Now On-line!!

- Summary for Decision Makers
- Section 1- intro
    - Introduction
    - Conceptual Framework
- Section 2 –
    - Impacts and Challenges
    - Scenarios
- Section 3 – Cross-cutting
    - Water Productivity
    - Ecosystems
    - Policies and Institutions
    - Poverty
- Section 4 - Sectoral
    - Rain-fed
    - Irrigated
    - Groundwater
    - Low-quality Water
    - Fisheries
    - Livestock
    - Rice
    - Land
    - Basins

Will There be Enough Water to Grow Our Food?

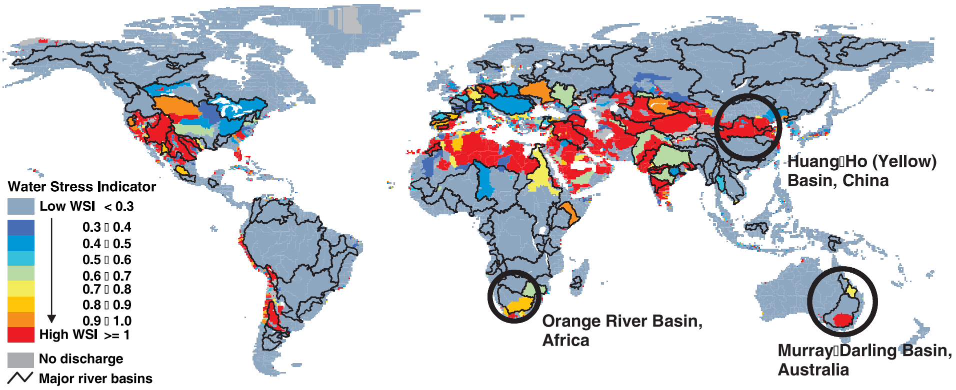
- Yes, if ...
- No, unless ...

A Third of the Population Has Already Suffered from Water Scarcity in 2000



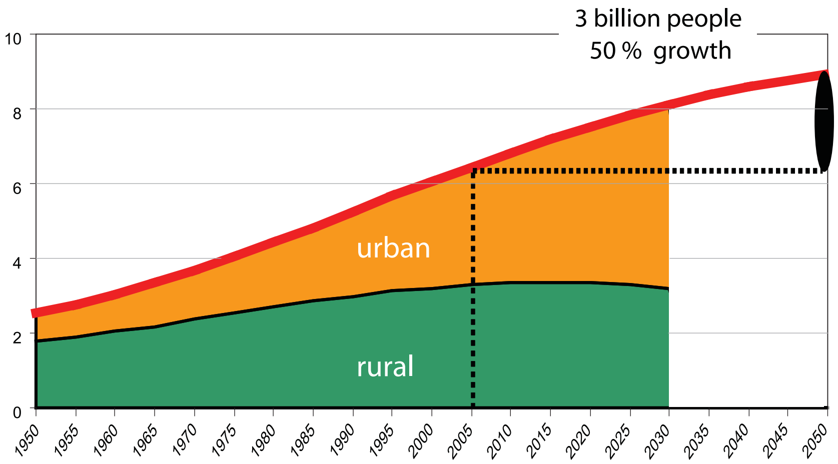
Source: *De Fraiture et al. IWMI*

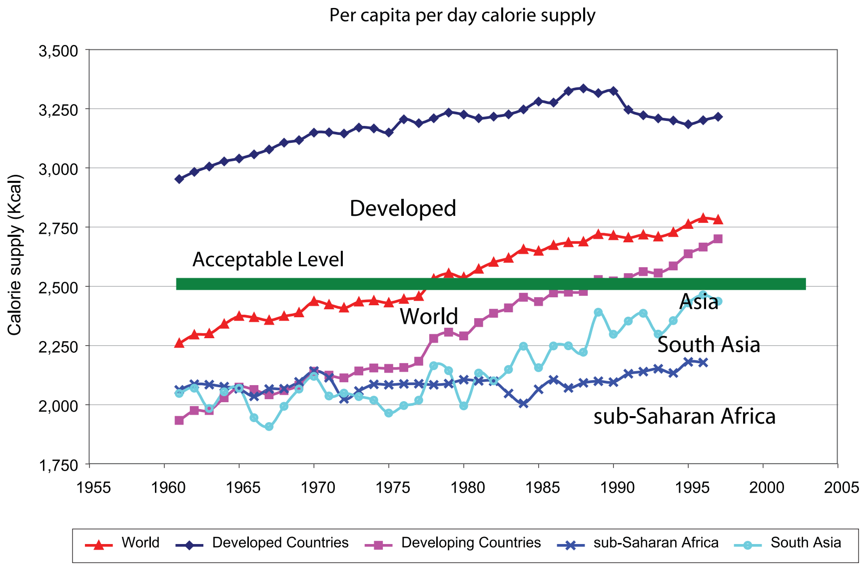
Environmental Scarcity



Source: *Smakhtin et al. 2004 International Water Resources Association*

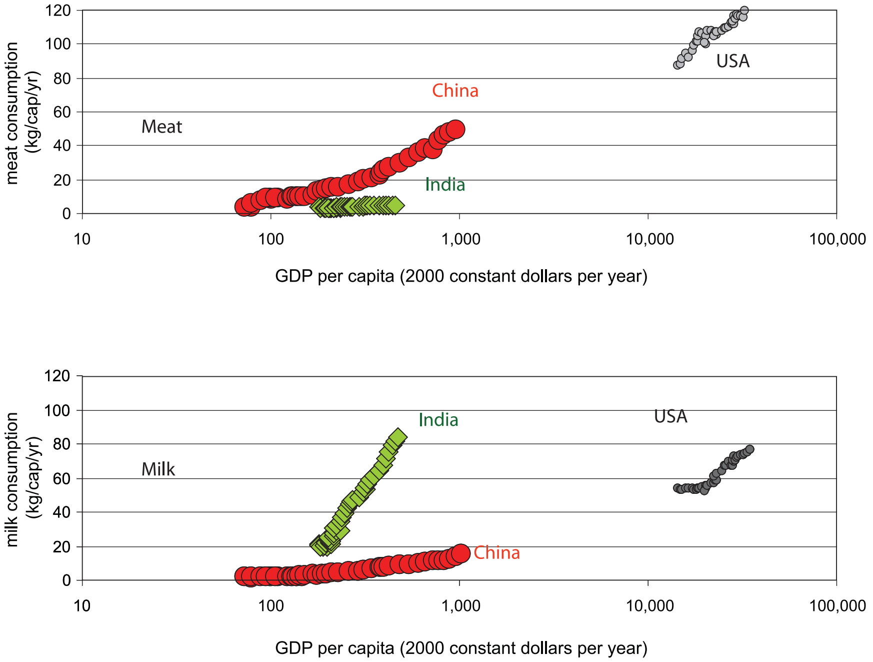
Drivers of Changing Food Demand





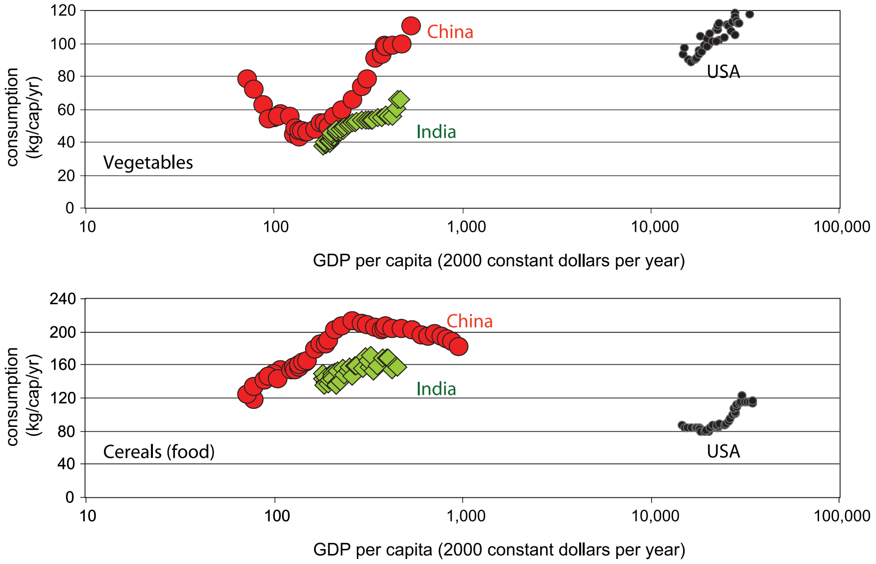
Source: FAOSTAT, 2001

Consumption and Income 1961-2000



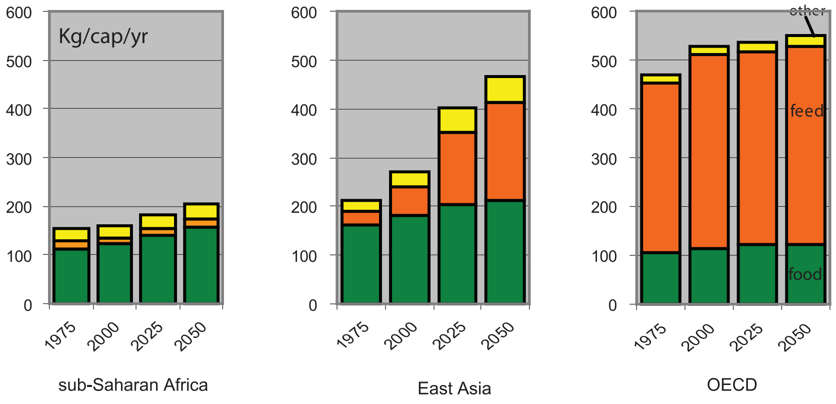
Source: De Fraiture, 2007

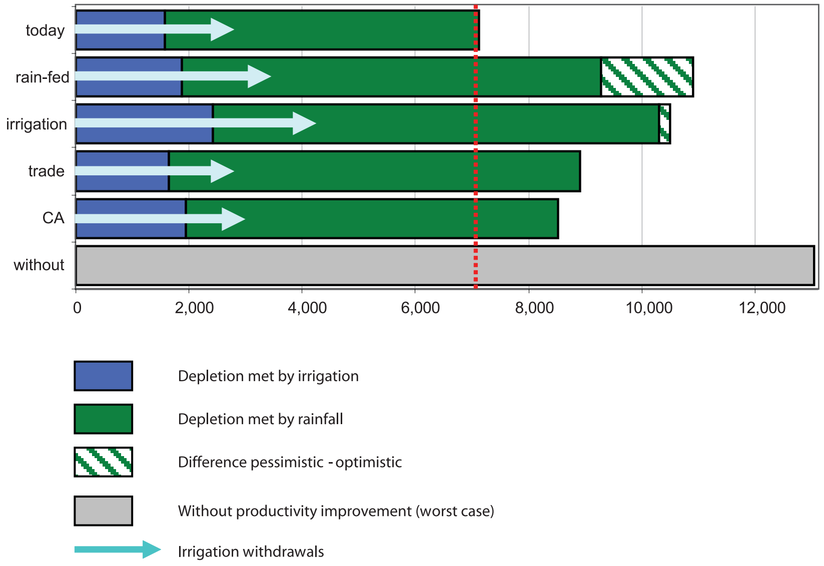
Consumption and Income 1961-2000



Source: De Fraiture, 2007

More Cereals





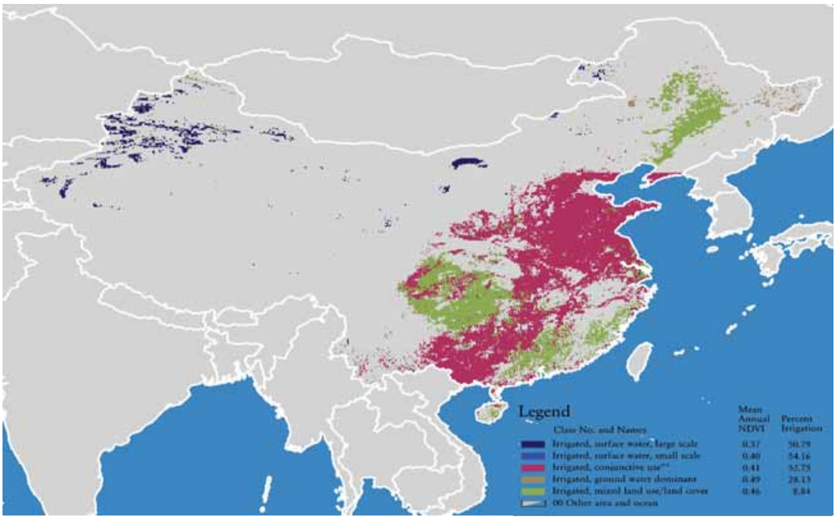
Source: WATERSIM simulations

Broad Conclusions from the CA

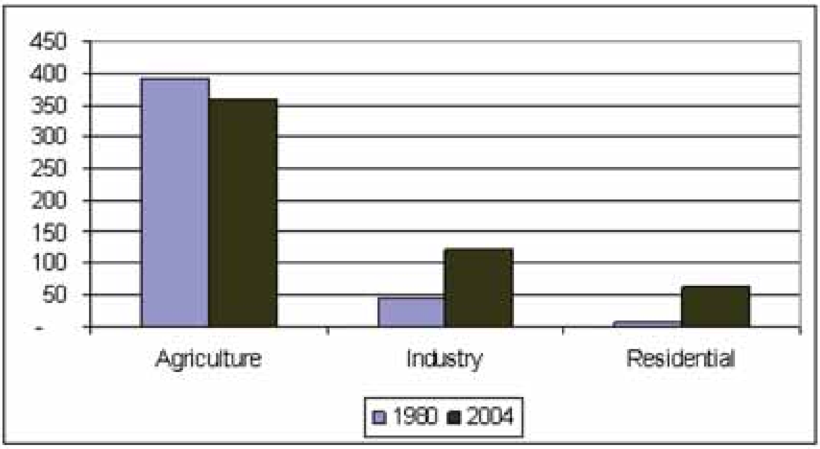
- More water is needed to grow our food, how much depends on what we do now;
- Food demand doubles by 2050, and under business-as-usual water demand will double;
- Major external drivers affecting the challenges;
- A third of the world population is already water scarce;

- Feeding the world and maintaining ecosystem services will require radical change;
- One-third of world's population live in basins which are already over-allocated, have less environmental flows and more pollution;
- New development means taking water from current users downstream.

China
Exporting and Importing "Virtual" Water

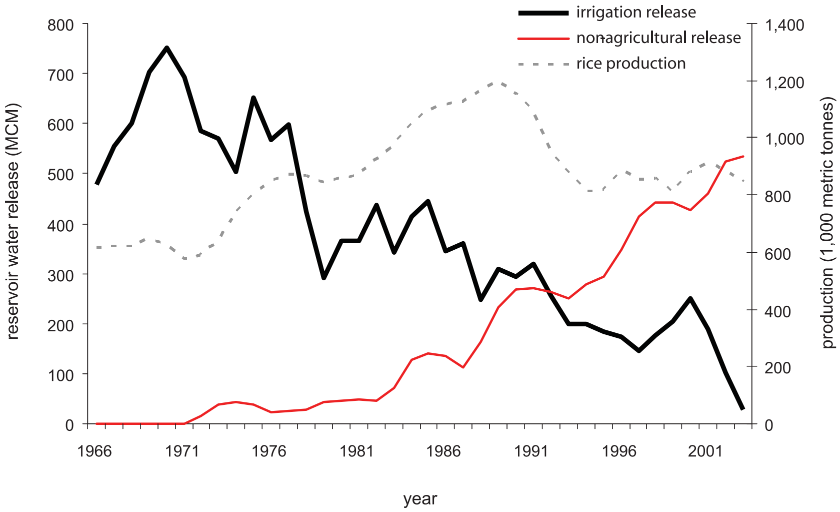


Water Use by Sector in China



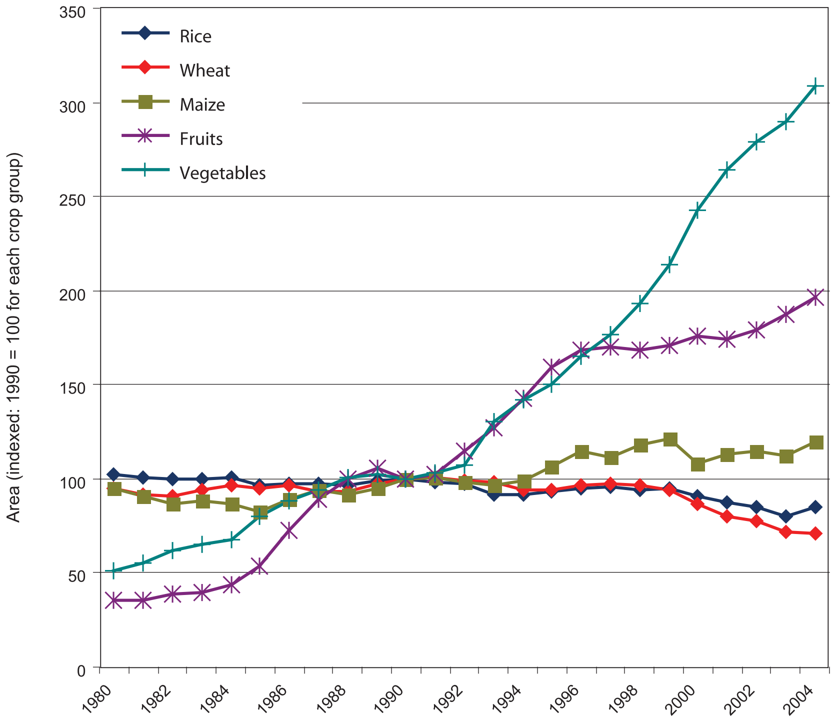
Source: Modified from Roland-Holst and Kahrl, 2007

Zhang He Irrigation System, Hubei, China



Source: IWMI, IRRI, CSIRO (L&W), Wuhan University, ZIS and LIS

Fruit and Vegetable Production Accelerating in China



Shifting to higher value crops for export and importing staple crops

Series of Issue Briefs Now being Produced

1. Reaping what we sow: Acting now to reduce the negative environmental consequences of agriculture
2. A little water can go a long way: Reducing rural poverty through better management of rainwater
3. Making a difference in water management: A minimum agenda on gender mainstreaming for researchers, practitioners and gender experts
4. Opening up options in closing river basins
5. Rice cultivation in the 21st century: How to feed more people, reduce poverty, and protect ecosystem services
6. Investing in irrigation: Why, how, and how much?
7. Reforming reform: Effective approaches to improving policies and institutions
8. Integrating livestock and water management to maximize benefits
9. Sustaining inland fisheries: Synergies and tradeoffs with water for agriculture
10. Managing water by managing land: Why addressing land degradation is necessary to improve water productivity and rural livelihoods

Will There be Enough Water to Grow Our Food?

- Yes, if ...
- No, unless ...

Presentation 3

What Components of NLRP will work given the Present Trends of Water Demand?

Anil D. Mohile
Former Chairman of Central Water Commission (CWC), New Delhi

The Overview of the Presentation

The Situation under which the "National Perspective Plan" of Water Transfers was Planned in late 1970s to early 1980s

- What changes have occurred, since then, in the situation?
- How do the changes affect the concept?

The detailing?

- What are the prospects of some components being implemented?
- Food insecurity;
- Largely agriculture-based economy;
- Unbalanced international trade;
- Total lack of individual initiative in water development;
- Lack of energy in rural areas;
- No serious pollution or water quality problems;
- Ecologic concerns on the backstage;
- Strong national viewpoint, regional or state viewpoints to be accommodated within; and
- More stable governments.

What Changes have Occurred, and are Occurring, since then, in the Situation?

- Changes in Indian agriculture;
- Changes in agricultural water technology and practices;
- Changes in concerns and objectives, with regard to water development;
- Changes in the world economic order;
- Changes in the Indian political order;
- Shrinking role of governments, worldwide;
- Growing concerns about climate change.

Changes in Indian Agriculture

- Agriculture remains an important, but not a leading sector of the economy;
- A recognition that the population depending on agriculture, needs to be reduced in a planned way;
- Shift in development objectives from "providing significant benefits from low investments to the 'poor' farmers," to "bringing farmers and the farm sector in the economic mainstream through large investments"
- Adjusting to the fact that 'pure' rain-fed agriculture is, and needs to vanish. All agriculture would involve sheds of irrigation.

Changes in Agricultural Water Technology and Practices

- An understanding, even at grass root level, of the essential unitary nature of the world's waters;
- A recognition that direct use of rain is also a water use;
- A definite shift from 'Integrated River Basin Management' to 'Integrated Water Resources Management'. Basins remain as important hydrologic units, but do not provide bounds to planning and management;
- An increasing recognition that agricultural water use includes the use for fish farming, animal husbandry, irrigated fodders, plantations and social forests, energy plantations etc.;
- A recognition that private groundwater use, if sustainable, has large advantages over public groundwater use and public surface water use;
- A recognition that in today's India, agricultural uses need not necessarily have a priority over other economic uses, and environment-related non-uses;
- A much wider energy availability in the rural settings;
- An unprecedented growth of private groundwater exploitation;
- In surface irrigation, a slow redundancy of the concept of command based on gravity flow.

The Changing Objectives of Water Transfers

- Equitable distribution of water remains a valid objective;
- Food security continues to be of some relevance, even under WTO regime;
- Rural poverty reduction through irrigation would be an important strategy. There are limits to urban migration and to in situ changes in rural livelihood patterns;
- Sustaining larger groundwater exploitation through a conjunctive use of surface water, and recharge, is a new objective;
- Enabling a larger industrial use and larger ecologic flows, along with increasing agricultural use, is an emerging objective.

What are the Prospects of Some Components Being Implemented?

Links	Attributes					
	International concerns	Inter-state concerns	Water for priority use	Water for severely water short areas	Important other benefits as concurrent products	Remarks
Ganga-Yamuna to Punjab? Haryana Rajasthan	Low	Medium		Yes		
Sarda-Ghagra towards west	High	Medium		Medium	Yes-Hydropower	
Gandak-Kosi to west	High	Low			Hydropower navigation and salinity control	
Bramhaputra-Ganga	Serious	Medium			Hydropower, navigation in lower Ganga	
Ganga-southern basins	Serious	Medium		Yes		
Southern tributaries of Ganaga	Low	Low		Yes		
Par-Tapi and west flowing to Mumbai	None	Low	Yes	No		
West flowing to Krishna Cauvery, and T.Nadu	None	High		Yes	Pumped storage in some	
Mahanadi Godavari to southern rivers	None	High	Yes	Yes		

Presentation 4

Policy Directions

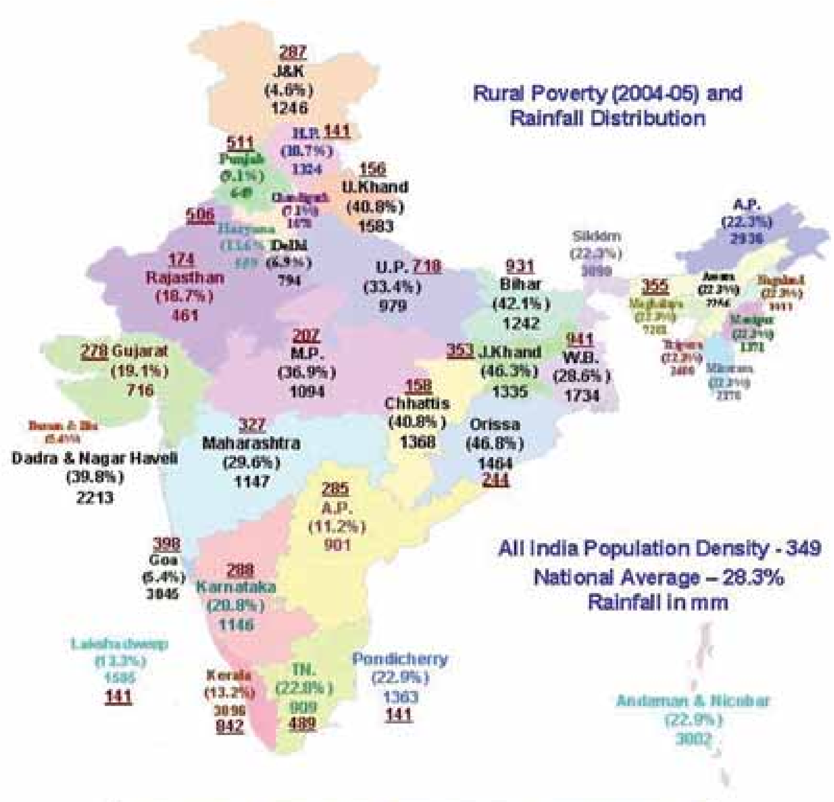
National Rain-fed Area Authority (NRAA)—Policy Directions

J. S. Samra, CEO
National Rain-fed Area Authority, New Delhi

IWMI-CPWF NATIONAL WORKSHOP

OCTOBER 9-10, 2007 NASC, NEW DELHI, INDIA

- 60 % of Indian and 80 % of world agriculture is un-irrigated;
- It is risky, uncertain, complex, diverse, fragile and under invested area;
- A broad spectrum of all 34 listed crops of India are grown as compared to very narrow range of Rice-Wheat or Rice-Rice in irrigated areas;
- In India 87 % of pulses, 77 % of oil seed and 50 % of cereals are contributed by rain-fed area. Livestock rearing, agro-forestry and outsourcing of income are also important;
- Capital intensive agriculture is distress prone like Bt cotton cultivation.



Underlined is Population Density 2003-04 (persons km^{-2})

The Aim

- Rainwater, soil and vegetation conservation;
- Enhancing and sustaining productivity, income and employment;
- Perspective plans, prioritization, innovative institutions, schemes or projects, emerging policies, managing risks, inputs, monitoring and evaluation etc.

Three Tiers of Elected Representatives Institutions (PRI) Policy

- Granted constitutional status to the general body of adults of (Gram Sabha) of a village or a group of hamlets- The 73rd Constitutional Amendment Acts 1993;
- This is an act of empowerment, decentralization and participatory development of villages;
- Out of 29 listed matters, 10 are related to agriculture, rainwater management and allied subjects;
- Haryali guidelines of Ministry of Rural Development proposes them to be Project Implementers (PI);
- Most of them lack capacities and technical expertise;
- 2.5 million elected representatives of all three tiers, about 10 % only get re-elected and sensitization or training is a challenge of repeated nature.

Social and Human Capital Related Policy

- Poverty, social backwardness, landless, assetless, out and in-migration is a common feature of rain-fed regions;
- US$ one billion (INR 46 billion)/ yr. Backward Region Grant Fund- untied (flexibility)- rain-fed area can access to these resources;
- The National Rural Employment Guarantee Act (2005) has become applicable to the entire country since October, 2007. Self-employment generation by creating assets is an overall aim;
- NREGA’s annual budget is expected to be around US$ 6.5 billion (INR 300 billion), 80 % activities are related to managing land, water and agriculture.

Right to Information Act (RTI)

- Transparency, prevention of leakages (if any), building confidence and enlisting communities participation are essential for quality output;
- Common guidelines of watershed management, operating joint accounts, maintaining records by villagers' nominee, public display of financial status on a board etc., are important instrumentalities;
- Re-enacted Agricultural Products and Market Committees (APMC) Act is leading to demand, supply and market-driven pricing structure MSP will cover risks.

Managing Risks and Distress

- Socioeconomic specific and regionally differentiated technological package;
- Special credit of longer period for entire income range and not crop specific;
- Deferment or waiving of interest or principal or both partially or entirely should be provided in the policy;
- Weather-based insurance derivatives;
- IT-based calamity relief for objectivity and quick delivery;
- More comprehensive assessment of drought losses including perennials, drop in livestock fertility, groundwater depletion and more power consumption for extracting groundwater etc.

Responding to Impacts of Climatic Changes

- Greater demand of bio-fuels and bio-energy is likely to shift cropping and farming systems;
- International prices of vegetable oils may escalate. India imported 4.1 million tonnes of edible oil in 2006-07 with an approximate import bill of US$ 2 billion;
- High international prices will trigger crop diversification and re-allocation of resources;
- Re-distribution of rainfall and water supplies will further compound the cropping and farming patterns.

Migration and Outsourcing

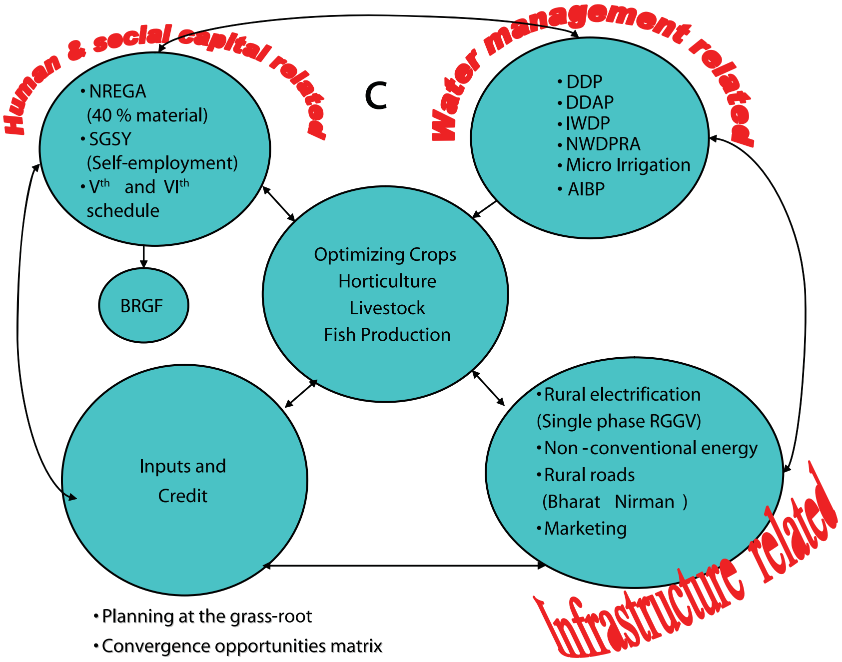
- Herders and graziers out- and in-migrate seasonally over long distances;
- Value addition by processing is not practical. They trade or sell live animals and raw primary products of wool, milk, meat etc. Negotiation of prices is restrictive.

Marketing

- There are endemic seed spices, gums, herbals and medicinal products;
- Their prices are highly volatile;
- Bulky and low-value commodities like pearlmillet (Bajra) etc., do not have much alternative uses, demands or value addition;
- Monoply purchase of cotton by the State Govt. of Maharashtra for 30 years was also one of the factors of distress;
- MSP should be determined as per input costs while procurement price should be market driven;
- Future trading by changing APMC acts;
- Local prices to be guarded against high subsidy in Europe and USA.

Benchmarking and Irrigation/Audit

- Lot of investments have gone into this sector;
- Regulatory authority set up in Maharashtra;
- Audit report is being printed after benchmarking;
- Half of the projects of Maharashtra had less than 50 % of performance;
- P I M (16 % area is covered in Maharashtra);
- Needs expansion to other states and irrigation systems.


Human & social capital related
• NREGA
(40 % material)
• SGSY
(Self-employment)
• V^th and VI^th
schedule
BRGF
C
Water management related
• DDP
• DDAP
• IWDP
• NWDPRA
• Micro Irrigation
• AIBP
Optimizing Crops
Horticulture
Livestock
Fish Production
Inputs and
Credit
• Rural electrification
(Single phase RGGV)
• Non -conventional energy
• Rural roads
(Bharat Nirman)
• Marketing
Infrastructure related
• Planning at the grass-root
• Convergence opportunities matrix

Presentation 5

Sustainable Agriculture and Trade

Yojindra K. Alagh
Former Union Minister of Science and Technology, Ahamadabad, Gujarat

Issues

- 'The Agro-climatic Paradigm' in India was meant to adjust agriculture to soil, water and climate (temperature; rainfall, level and variation);
- Self-sufficiency was to give way to trade: for a region, for India;
- Trade would ease the non-renewable resource constraint, but It did not happen;
- Global Agricultural Markets are highly distorted;
- The Asian meltdown was a blow to diversification and trade in agriculture;
- Indian policies were not very agriculture-friendly in a WTO-dominated trading world;
- Hopefully the worst is behind us.

The Agro-climatic Paradigm

- Inaugurating the Indian Society of Agricultural Economics meeting at Rahuri in Dec.1998 on 'Agricultural Trade and Sustainable Development' (Y.K.Alagh, 1999), the present author spoke of "15 agro-climatic zones taking into account soil, climate and water availability…127 agro- ecological ones…"
- "There is an imperative need for conservation" (Ibid., pp.1-2)

The Global Context

- It has been argued by the present author and others that agricultural diversification in India is basically driven by domestic demand (Y.K. Alagh, Shastri Memorial Lecture, reprinted in ICAR, Agricultural Transformation in India , 1995.);
- However, international trade would also hasten the process(Y. K. Alagh, India's Agricultural Trade, Indian Economic Journal, First Dantwala, Memorial Lecture, 1999). This follows from trade theory and was welcomed (Y.K. Alagh, India's Agricultural Trade with the ESCAP Region, in U.N., Agricultural Trade in the ESCAP Region, Studies in International Trade, Vol.10, U.N. New York, 1995);
- It has been argued that the trading between agricultural agro-climatic regions were also those that had more often than not, followed sustainable land and water

development policies (Y.K. Alagh, Inaugural Address, Indian Society of Agricultural Economics, Parbhani 1998; IJAE 1999);

- There was, therefore, considerable synergy in trade, diversification and sustainable development. Economists supported the recommendations of studies like the CII-Mckinsey Report on diversification and agricultural markets.

Is Trade Water Saving?

- "Dry land horticulture, dairying products and spices are all fast growing exports.
- They are also grown in dry land areas, where water management and land development programs have succeeded.
- A typical pattern or example is to switch over from a low-yielding mono-crop cereal to a short duration high-yielding cereal, followed by a non-cereal food or non-food crop.
- Alternately it may move to fodder, to tree crops, or in some areas to horticulture." (Y.K. Alagh 1999, p.4).

1998

- In 1998, the East Asian meltdown was known to Indians, but the Government did not notice it;
- In the Dec. 1998 address to the ISAE, I argued that in 96/97 growth of agriculture trade fell to around 1 %. "In1998,the floor just fell out from agricultural trade." Growth was minus 6 % in Jan-Mar 98 and minus 16 % in Apr/Jun 98;
- I pointed out that as a minister attending the Hong Kong World Bank IMF meeting "They were all clear that that the meltdown would last. Back home none of the dream merchants would bite."(Y.K. Alagh 1999, p.2).

The Meltdown

- The East Asian slowdown led to a slowdown in the diversification of the agrarian economies of the NIEs. We developed a simple indicator of diversification namely the change in the index of livestock production in a country divided by the index of agricultural production;

- According to the World Development Indicators, the long-term annual GDP growth rate through 1997 was 7 to 8 % for Indonesia, Malaysia, Thailand and the Republic of Korea, respectively. In these countries;
  - Between 1984 to 1994, the incremental livestock to agricultural production ratio was 2.12, 2.18, 2.59 and 2.56, respectively, for these countries; and the GDP growth of these countries went down to 4.7 %, 2.9 %, 0.3 % and 4.4 %;
  - Between 1994 and 1999, incremental livestock to agricultural production ratio went down to minus 1.79, 1.01, minus 1.61 and minus 0.72; and
  - Data on vegetable and fruit production is available only for the 1990s (FAOSTAT), and the incremental vegetable to cereal production ratio is minus 1.14 in Indonesia, minus 2.58 in Malaysia, minus 0.3 in Thailand and minus 1.43 in South Korea from 1994 to 1999.
- The Indian story was different;
- At a FAO/UNDP seminar at Seoul country papers showed the price paid; A fast growing country like Vietnam saw a decline in agricultural growth, inequality and reversal of diversification. (see, Son, Que, Dieu,Trang of IAE and D Beresford 2006; also Y. Alagh 2006).

Edible Oil Import

Year	% of Import/ Production
• 1991-92	14.50
• 1992-93	21.96
• 1993-94	72.12
• 1994-95	06.27
• 1995-96	18.83
• 1996-97	22.94
• 1997-98	25.11
• 1998-99	44.59
• 1999-2000	84.71
• 2000-01	90.49
• 2001-02	75.02
• 2002-03	95.08

Tarrifs

Name of items 04 applied	Rate of Tariff	Bound Rate of Tariff
• Soybean Oil (crude)	45 %	45 %
• Soybean Oil (refined)	45 %	45 %
• Crude Palm Oil	65 %	300 %
• RBD Palmolien and Refined Palm Oil	75 %	300 %
• Rapeseed / Mustard Oil (crude)	75 %	75 %
• Rapeseed / Mustard Oil (refined)	75 %	75 %
• Sunflower and Safflower Oil (crude)	75 %	300 %
• Sunflower and Safflower Oil (refined)	85 %	300 %
• Other Edible Oils including Coconut Oil (crude)	75 %	300 %
• Other Edible Oils including Coconut Oil (refined)	85 %	300 %
• Oilseeds	30 %	100 %

Cotton Imports/Exports

Year	Production	Import	Export	Availability*	% of Import to Availability	% of Import to Production
1990-91	1,672.80	0.00	497.14	1,175.66	0.00	0.00
1991-92	1,650.70	0.00	160.34	1,490.36	0.00	0.00
1992-93	1,938.00	138.13	63.74	2,012.39	6.86	7.13
1993-94	1,825.80	3.82	312.56	1,517.06	0.25	0.21
1994-95	2,021.30	80.80	70.75	2,031.35	3.98	4.00
1995-96	2,186.20	69.62	33.28	2,222.54	3.13	3.18
1996-97	2,419.10	2.92	269.58	2,152.44	0.14	0.12
1997-98	1,844.50	9.97	157.53	1,696.94	0.59	0.54
1998-99	2,089.30	57.40	41.96	2,104.74	2.73	2.75
1999-2000	1,960.10	237.40	15.91	2,181.59	10.88	12.11
2000-01	1,618.40	212.36	29.7	1,801.06	11.79	13.12
2001-02	1,700.00	387.04	8.23	2,078.81	18.62	22.77
2002-03	1,482.40	233.85	10.8	1,705.45	13.71	15.78

Sugar

- There are a number of years in the 1990s when sugar imports were around a million tonnes or more; 94/95,98/99.99/00 (MOA 2004, p.1,480);
- The Nerlovian nature of the sugarcane economy is known (APC, 82 Report);
- High imports exaggerated the cane cycle. Tariffs, earlier low are now at 60 % +.

Indian Biases?

- "We report less disprotection of Indian agriculture in the 1990s than in earlier studies." (See K. Mullen, D.Orden and A.Gulati, IFFPRI 2005);
- The context is going to be difficult for India. It has to be recognized that;
    1. India does not discriminate against agriculture as much as it did in the past;
    2. In the case of rice and wheat a new playing field is there;
    3. India subsidizes agriculture. Indian subsidies will be up for discussion in the next round. Its reform process will have to be WTO compatible.

A Kafkaesque World

- In fact, while India was importing low-water consuming crops like cotton and oilseeds, it was exporting high-water using crops like rice and sugarcane, and in the first half of the this decade its grain exports were high;
- No one could complain, because their subsidies were much higher;
- It's an amazingly distorted world.

Counterfactuals

- The percentage of import of edible oils to domestic production was 95 % in 2002-03. Natural cycle of 18 months in case of sugarcane crop, for instance, has been distorted by imports of sugar during the second half of the decade of 1990s. Cotton imports of a sixth to a fifth of demand are seldom seen as a problem;
- Counterfactuals (Alagh 2005) have shown that achievable targets in instruments like tarrifs, taxes, reduced effective interest rates and better marketing support can be integrated with pricing recommendations, which are alternates with MSP

increases. These should become the standard practice. This integration would be market-friendly and WTO-compatible in the sense that it would not show in AMS calculations and would serve the purpose of policy;

- A roadmap for principal crops not based on historical costs but opportunity costs at the margin will have to be developed so that technological progress and India’s competitive advantage such as bright sunshine and cheap labor are given a free reign to play The farmer must be given incentives of a pricing and non-pricing nature to internalize costs of transition for a well defined and limited period. Higher level policies of support have to be implemented to meet the costs of a competitive agriculture in the medium term of 3 to 5 years.

Regional Aspects

- Since the early 1990s, economic policy in India has neither the intention, nor the werewithal to determine or significantly influence sectoral and regional aspects of economic development. The Structural Adjustment Program in 1992, was on the explicit basis that the purpose of economic policies would be to replace quantitative interventions with fiscal and financial policies. Also tax and tariff rates were to be reduced in level and spread. Regional and sectoral selectivity like special concessions or exemptions were, therefore, to be rationalized. The objective would be to raise the aggregate growth rate, remove hindrances to business enterprises and expect the benign role of the market to also trigger growth in backward regions;
- In the 1990s there was higher growth in crops, which grew in the rain-fed regions as the former ‘Green Revolution States’ showed growth fatigue. But overall growth in agriculture fell. Hence, in spite of comparatively faster growth in rice as compared to wheat and as compared to earlier periods, the poorer regions did not do very well. This was accentuated by a distinct anti-grain bias in economic and technology policy that hurt the growth prospects of the predominantly poor rice growing regions. Also oilseeds, the main crop into which farmers diversified in these regions, suffered on account of large imports with low tariffs. Successful diversification into oilseeds in the 1980s in backward regions, particularly in the Central and Eastern region suffered. Raw cotton is not a big crop in the East, but it is in Central India, and large imports again led to shrinkage in area in the dry poor areas of the Deccan.

Policy Needed

- IWMI may consider a work program of delay of WTO agreements on sustainability issues in large water-scarce countries like China and India;
- There is an urgency about this since, the agricultural slump is over and conditions are perking up;
- A Monitoring and Early Warning Mechanism may be a beginning.

References

- Yoginder, A.K. 1995. India's Agricultural Trade with the ESCAP Region, in, U.N., *Agricultural Trade with the ESCAP Region*, Studies in International Trade, Vol. 10, U.N. New York.
- Yoginder, A.K. 1998. Agricultural Trade and Policies, *Indian Economic Journal*, First Dantwala Memorial Lecture, Vol.46, No.3, pp.56-65.
- Yoginder, A.K. 1999. Agriculture, Trade and Sustainable Development, *Indian Journal of Agricultural Economics*, Jan-March.,pp.1-5.
- Yoginder, A.K. 2002a. Emerging Institutions and Organisations: Some Aspects of Sustainable Rural Development, in Chopra, K. et al., below :reproduced in G.C. Malhotra (Ed.), *Fifty Years of Indian Parliament*, New Delhi, Lok Sabha Secratariat, 2002, pp.491-504.
- Yoginder, A.K. 2003. Agricultural Price Policy in an Open Economy, *Tenth Dharm Narain Memorial Lecture*, Institute of Economic Growth, Delhi.
- Yoginder, A.K. 2004. *State of the Indian Farmers: A Millennium Study, An Overview*, Academic Foundation, New Delhi.
- Yoginder, A.K. 2006. *Agricultural Reform and Transformation in Vietnam- Comments*, FAO.
- Son, Que, Dieu and Trang of IAE, MARD and D Beresford. 2006**.** *Agricultural Transformation in Vietnam*, Bangkok, FAO.

Presentation 6

Groundwater Irrigation in India

Future Directions and Policy Issues

B. M. Jha, Chairman
Central Groundwater Development Board, New Delhi

Groundwater Irrigation

Facts

- Over the past 50 years, expansion of groundwater irrigation globally has played a lead role in food security;
- More reliable water delivery and declining extraction costs due to advances in technology and, in many instances, government subsidies for power and pump installation encourages private investment in groundwater irrigation.

Global Scenario

- Among the major countries, India has over 50 % of its area irrigated from groundwater, followed by the USA (43 %), China (27 %) and Pakistan (25 %);
- According to a report of the World Commission for Water, aquifers are being mined at an unprecedented rate;
- About 10 % of the world's agricultural food production depends on using mined groundwater. However, this should not be encouraged.

Indian Scenario

- In India, the area irrigated by groundwater rose from nearly 6.5 Mha in 1950 to around 70 Mha at present;
- Development of groundwater to meet irrigation requirements has led to the over-exploitation of groundwater resources in many areas where water tables have been falling at an alarming rate—often one to three meters a year;
- One of the world's major grain producing areas ('breadbaskets') i.e., Punjab is now suffering from groundwater scarcity;
- The unreliable power supplies combined with weak management of groundwater resources greatly constrained the growth of irrigated agriculture;
- Excess use of pumps for irrigation, domestic and industrial use is degrading groundwater resources;
- The point has been reached in some areas that the overexploitation is posing a major threat to the environment, health and food security.

Groundwater Availability:

vis-a-vis Utilization

- The occurrence and distribution of groundwater in space and time is highly variable due to the diversified hydrogeologic conditions;
- Broadly two group of water bearing rock formations have been identified depending on characteristically different hydraulics properties, viz:
  - i. Porous formations, which can be further classified into unconsolidated and semi-consolidated formations having primary porosity; and
  - ii. Fissured formations or Consolidated formations, which have mostly secondary or derived porosity.

Estimation of Groundwater (GW) Resources

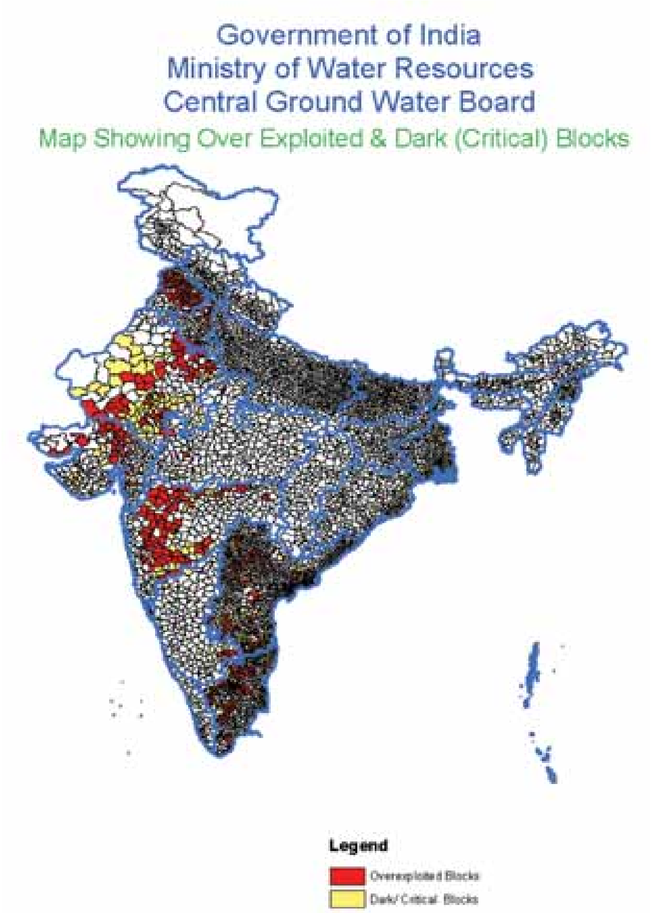
- Replenishable GW resources estimated jointly with the State Depts. and NABARD as per GEC 1997 norms:
- Present estimation of GW Resources (as on March, 2004)
    - Total Annually Replenishable GW Resource – 433 bcm
    - Net Annual GW Availability – 399 bcm
    - Net Annual GW Draft – 231 bcm
    - Out of which 92 % draft is for irrigation
- In-storage GW Resources (below zone of fluctuation) – 10,800 bcm

GW Development Scenario

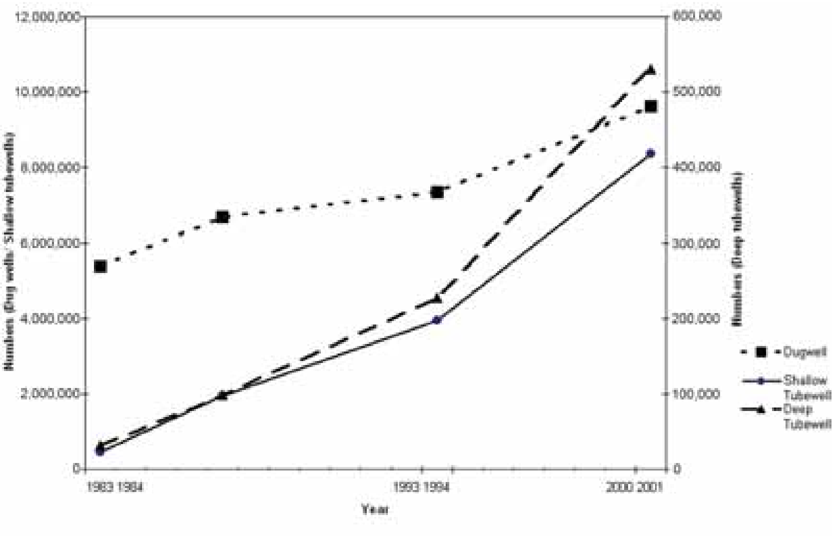
- Delhi, Haryana, Punjab, Rajasthan, Gujarat, Tamil Nadu

Groundwater Development Scenario

- Total Assessment Units (Blocks / Mandals/ Talukas) – 5,723
- Overexploited Units – 839
- Critical Units - 226
- Semi-critical Units – 550
- Safe Units – 4,078

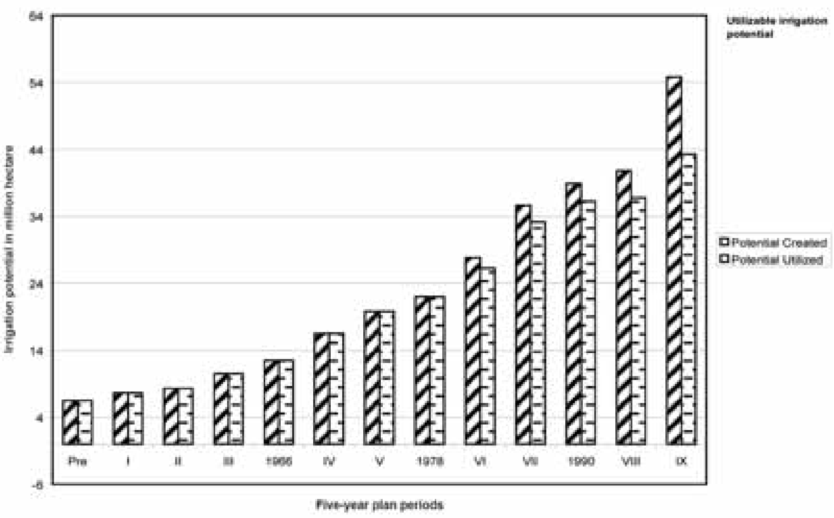


Growth of Groundwater Abstraction Structures in India



Source: Minor Irrigation Census, 2001

Irrigation Potential Created/ Utilized through Groundwater in the Country over Plan Periods



Source: Ministry of Water Resources website

Future Strategies:

Management Options

Groundwater Development in Alluvial Plains of Eastern and North-Eastern India

- Scientific studies have proven that ample reserve of groundwater is available in the areas underlain by Indo-Gangetic and Brahmaputra alluvial plains in the Eastern and North-Eastern parts of the country;
- One of the management measures could be to adopt the concept of ***Virtual Water.***

Groundwater Development in Flood Plain Aquifers

- Flood plains of rivers are normally good repositories of groundwater and offers excellent scope for development of groundwater;
- A planned management of water resource in these tracts can capture the surplus monsoon runoff, which otherwise goes waste;
- The strategy involves controlled withdrawal of groundwater from the flood plains during non-monsoon season to create additional space in the unsaturated zone for subsequent recharge/infiltration during rainy season.

Groundwater Development in Coastal Areas

- Many parts of the coastal areas of India have thick deposits of sediments ranging in age from Pleistocene to recent, which have given rise to multi-aquifer systems of good potential;
- However, development of groundwater from such aquifers needs to be done with caution, and care should be taken to ensure that overexploitation of resources does not lead to saline water intrusion.

Groundwater Development from Deep Aquifers

- The stage of groundwater development is rather high in the States of Haryana, Punjab and Rajasthan, and a large number of overexploited and critical assessment units are found in these states;
- Studies by CGWB in the Indo-Gangetic Basin in Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal have revealed the existence of deep-seated aquifers storing voluminous quantity of groundwater.

Groundwater Development in Hard Rock Areas

- The hard rock areas are characterized by considerable heterogeneity and anisotropy and the aquifers are normally discontinuous and of limited groundwater potential;
- In spite of their limited potential, these aquifers play an important role in meeting the drinking, agricultural and industrial needs in the peninsular shield areas of the country.

Groundwater Development in Waterlogged Areas

- Surface and groundwater should be viewed as an integrated resource and should be developed conjunctively in a coordinated manner and their use should be envisaged right from the project planning stage.

Rainwater Harvesting and Artificial Recharge to Groundwater

- Rainwater harvesting and artificial recharge are effective methods for augmenting groundwater resources and for arresting/reversing the declining trends of groundwater levels.

Regulation of Groundwater Development

- Groundwater regulatory measure is an effective mechanism to check overexploitation of groundwater under extreme situations;
- Regulatory measures in India are implemented both at the Central and State level;
- The Central Groundwater Authority, constituted under Environment (Protection) Act of 1986 is playing a key role in regulation and control of groundwater development in the country;
- Ministry of Water Resources has prepared and circulated a Model Bill to all States and Union Territories in 1970, which was re-circulated in 1992, 1996 and 2005 for adoption.

Water Saving Measures

- Water saving practices like adoption of micro irrigation, sprinklers and drip systems can save a substantial quantity of water;
- Less water intensive crops , sharing of water and rotational operation of tubewells can provide viable solutions for balancing agro-economics with environmental equilibrium;
- Cultivation of salt-tolerant crops in areas underlain by brackish/saline water with mixing can be a viable solution.

Policy Issues

The Country Faces A Paradoxical Situation With

- Overexploited areas resulting in decline in groundwater level while;
- vast areas with sub optimal development.

The Policy Issues Should Include

- Implementation of effective regulation/ augmentation measures in groundwater stress areas with priority in OE/critical assessment units;
- Implementation of exhaustive groundwater development plans in areas having low stage of groundwater development.

Energization and Pricing Policy in the Irrigation Sector

- The overall pricing structure in groundwater irrigation is mainly dependant on power tariff;
- An economically as well as environmentally viable pricing policy in this sector needs to be evolved at the earliest.

Ownership and Sectoral Allocation of Groundwater

- A judicious mechanism in this regard is required to be developed at an early date;
- Various steps have been taken by the MOWR to address the issue of ownership and sectoral allocation;
- The expert committee report of the planning commission in this regard. has been submitted recently.

Challenges

- The increasing dependence on groundwater necessitated a reorientation of the strategies of groundwater management to ensure its long-term sustainability;
- The emphasis on management does not imply that groundwater resources in India are fully developed;
- Focus on development activities must now be balanced by management mechanisms for sustainability;
- The power tariffs need to be revised keeping socioeconomic considerations;
- The time has come, that we must realize the dependency on groundwater for our varying requirements and take necessary steps to avert the crisis.

Presentation 7

Restoration of Livelihoods of Involuntarily Displaced Communities:

Perspectives from Ujjani and Sardar Sarovar Projects

**Madar Samad and **Zankhana Shah*
**Director South Asia, IWMI, Hyderabad, India*
**Former Consultant, IWMI-TATA Water Policy Program, India

INTERNATIONAL WATER MANAGEMENT INSTITUTE
HYDERABAD

The Problem

Due to deficiencies in the resettlement and rehabilitation process a significant number of displaced families are more impoverished than before displacement.

Key Question

Why is resettlement and rehabilitation (R&R) of involuntarily displaced population continues to be a difficult problem, despite the vast national and international experiences in R&R, and the existence of several guidelines on resettlement management?

- **Saifuddin Soz Committee Report: "***due to* ***defects in policy*** *and* ***prescribed procedures (i.e., institutional defects)*** *there are many failures in the rehabilitation effort, and is also not in accordance with the supreme court order"* (The Hindu, April 17, 2006)

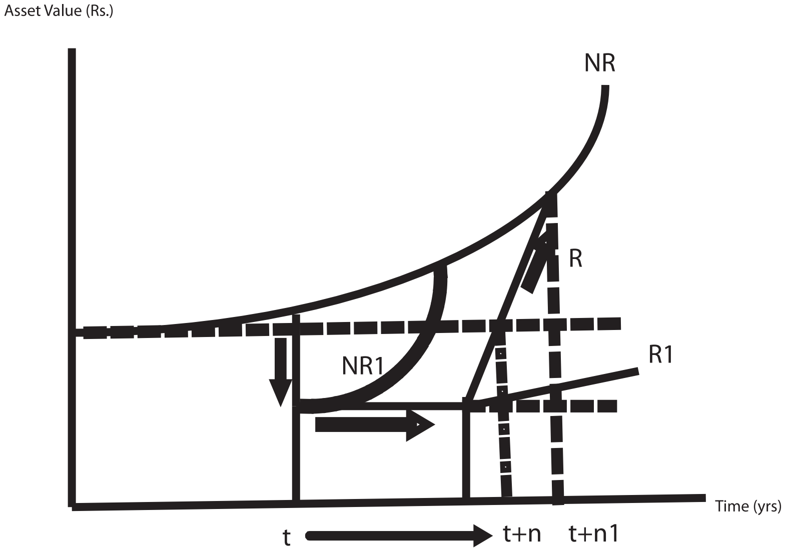
Past Scholarship

- Many of past studies make broad generalizations on informed opinions or supported with limited data;
- Assessments of short impacts i.e., in the immediate period after resettlement and do not assess longer term impacts;
- Most studies are based on the premise that displacement leads to impoverishment, and fail to adequately take into account new livelihood opportunities offered in the relocated sites.

Objectives

- To assesses the short- and long-term impacts of resettlement and rehabilitation on the living standards of Project Affected Families (PAFs);
- To determine the extent to which national/state policies and procedures have enabled PAFs to restore and improve their livelihood;
- To determine whether PAFs have taken advantage of non-project related opportunities, if any, to restore and improve their standard of living.

Post Displacement Livelihood Restoration Pathway

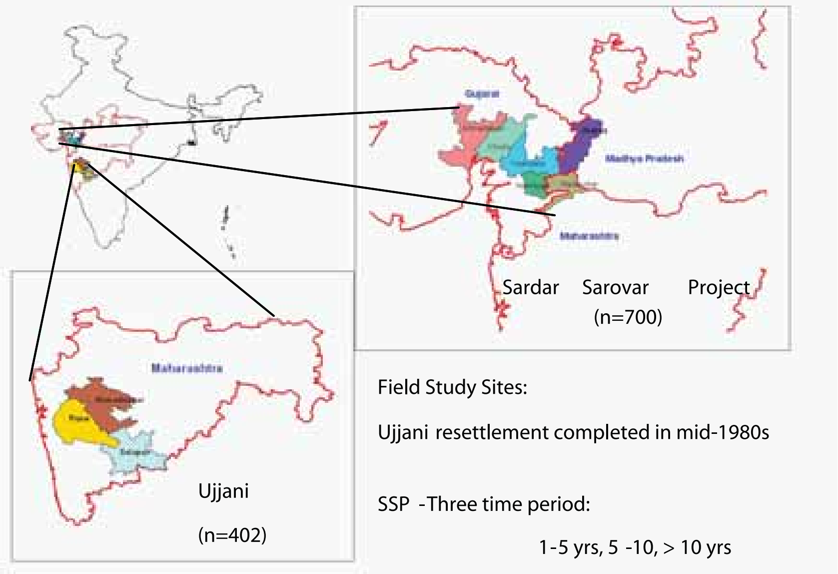


Hypothses

Hypothesis 1: Negative short-term consequences of displacement are compensated by the longer-term benefits generated from enhanced socioeconomic opportunities created in the newly developed relocation site.
Hypothesis 2: With proper counter risk policy and approaches, short-term adverse effects can be largely arrested, and some even fully prevented, while others considerably mitigated, and thus people's livelihood are restored much earlier.

Method of Study

- Policy Reviews: National and State
- Analysis of litigations and petitions filed by PAFs
- Field Survey



Field Study Sites:

Ujjani resettlement completed in mid-1980s

SSP -Three time period:

1-5 yrs, 5 -10, > 10 yrs

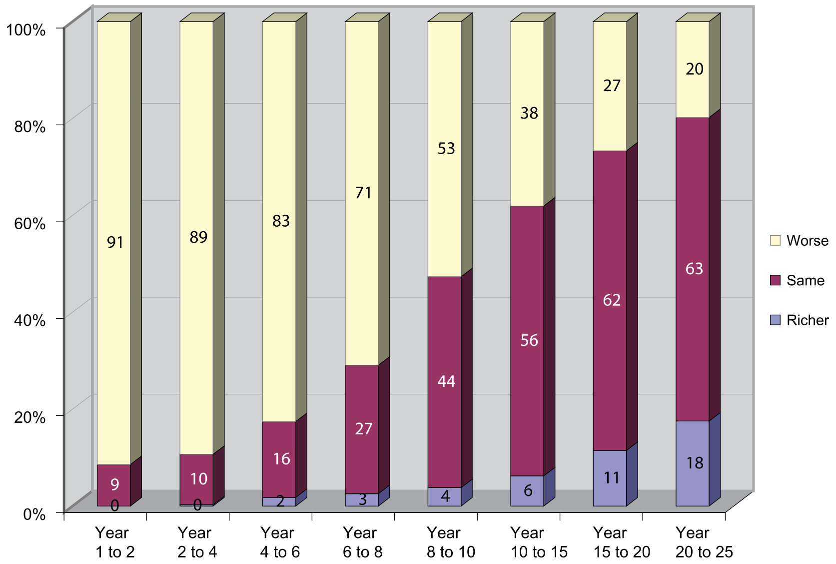
Field Survey

Research Question:

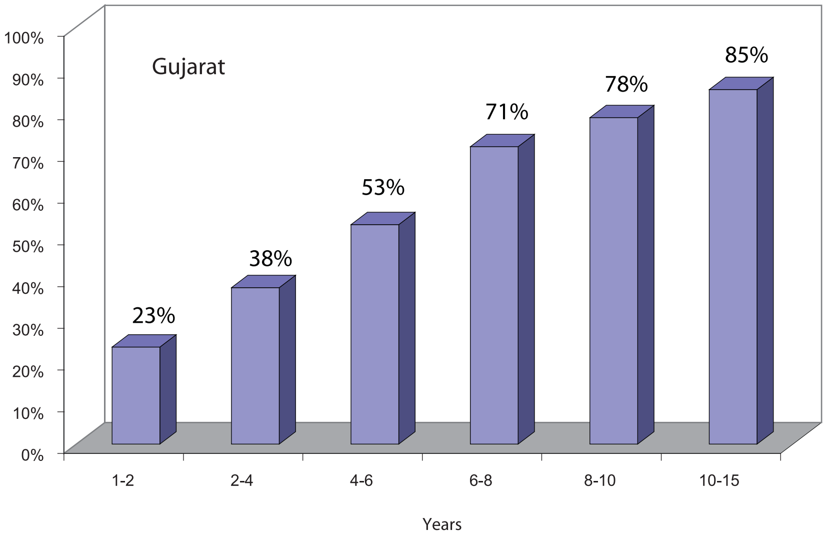
How have PAFs in Ujjani and SSP fared over time?

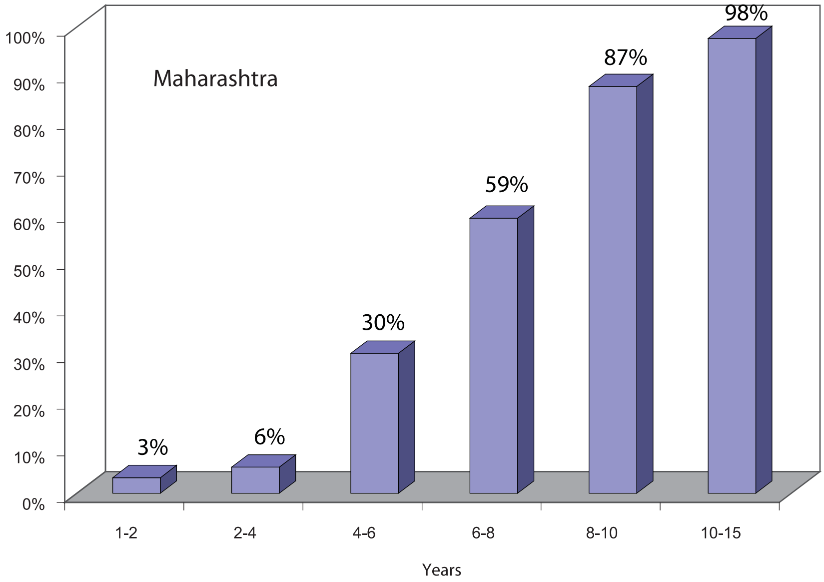
- Are they better-off than before displacement?
- Worse-off than before displacement?
- No change?

Ujjani-Restoration of Livelihoods of Displaced Population with Time

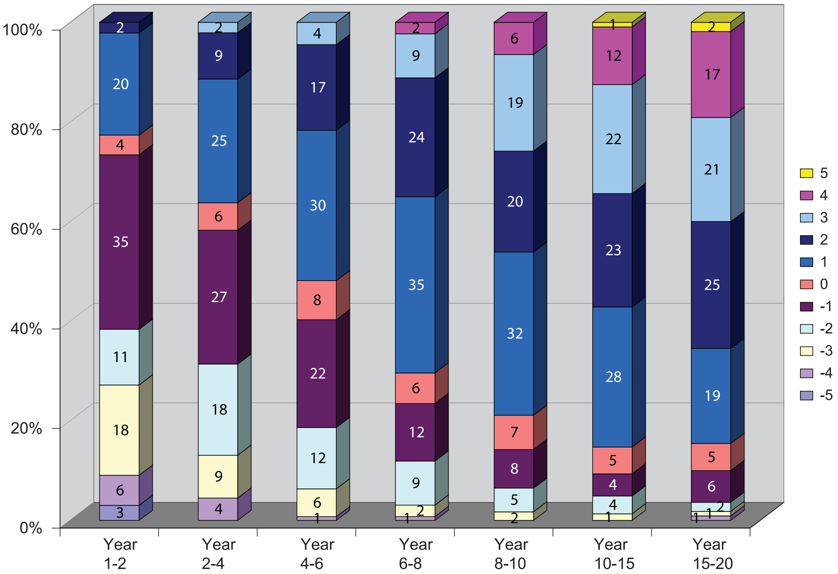


Livelihood Restoration With Time SSP

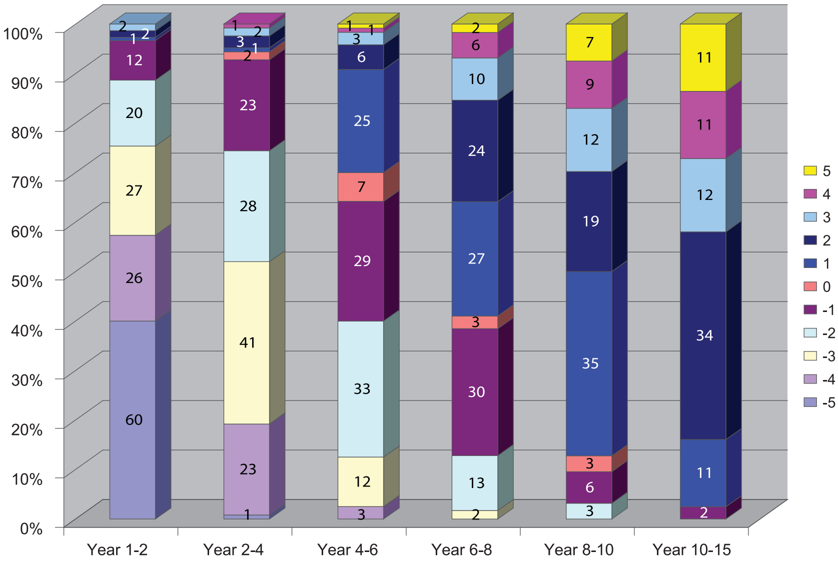




Restoration of Livelihoods of Displaced Population with Time in SSP-Gujarat



Restoration of Livelihoods of Displaced Population with Time in SSP- Maharashtra



Reasons Given by the Household for the Negative Outcome. Ujjaini

Reasons	Year 1-2 (N=291)	Year 2-4 (N=158)	Year 4-6 (N=64)	Year 6-8 (N=39)	Year 8-10 (N=20)	Year 10-15 (N=13)	Year 15-20 (N=13)
Water Problems	16	9	25	10	35	31	8
Allocated Degraded Land	15	21	15	0	10	23	0
Crop Failure	2	3	3	0	10	0	0
Poor Housing	29	10	9	0	0	8	15
Social Disarticulation and Despair	4	3	3	0	0	8	8
Lack of Wage Employment	5	12	20	0	10	8	23
Lack of Basic Facilities	24	37	17	0	30	0	46
Others	4	6	7	0	5	23	0

Reasons Given by the Household for the Positive Outcome. Ujjaini

Reasons	Year 1-2	Year 2-4	Year 4-6	Year 6-8	Year 8-10	Year 10-15	Year 15-20
Received and Land Compensation	28	11	6	4	5	4	1
Improved Access to Social Facilities	30	7	24	20	36	45	59
Better Living Conditions	21	25	13	23	18	18	20
Improved Housing	5	29	27	20	14	12	1
Good Incomes from Cultivation	16	28	30	34	28	21	19

Reasons Given by the Household for the Negative Outcome – SSP Maharastra

Reasons	Year 1-2 (N=131)	Year 2-4 (N=65)	Year 4-6 (N=34)	Year 6-8 (N=22)	Year 8-10 (N=3)	Year 10-15	Year 15-20
Water Problems	2	3	0	9			
Allocated Degraded Land	27	24	16	16			
Crop Failure	3	8	0	0			
Poor Housing	8	5	0	0			
Social Disarticulation and Despair	44	30	28	25			
Lack of Wage Employment	1	6	12	9			
Others	4	9	6	3			
Lack of Basic Facilities	11	34	62	64			

Reasons Given by the Household for the Positive Outcome – SSP Maharastra

Reasons	Year 1-2 (N=17)	Year 2-4 (N=49)	Year 4-6 (N=66)	Year 6-8 (N=71)	Year 8-10 (N=68)	Year 10-15 (N=59)	Year 15-20 (N=8)
Received Land as Compensation	29	4	12	4	3	2	0
Improved Access to Social Facilities	24	8	47	54	47	53	25
Better Living Conditions	12	10	15	25	35	42	75
Improved Housing	18	41	5	4	4	2	0
Good Incomes from Agriculture	18	37	21	13	10	2	0

Reasons Given by the Household for the Negative Outcome – SSP Gujarat
Percentage of Households

Reasons	Year 1-2 (N=291)	Year 2-4 (N=158)	Year 4-6 (N=64)	Year 6-8 (N=39)	Year 8-10 (N=20)	Year 10-15 (N=13)	Year 15-20 (N=13)
Water Problems	16	9	25	10	35	31	8
Allocated Degraded Land	15	21	15	0	10	23	0
Crop Failure	2	3	3	0	10	0	0
Poor Housing	29	10	9	0	0	8	15
Social Disarticulation and Despair	4	3	3	0	0	8	8
Lack of Wage Employment	5	12	20	0	10	8	23
Lack of Basic Facilities	24	37	17	0	30	0	46
Others	4	6	7	0	5	23	0

Reasons Given by the Household for the Positive Outcome – SSP Gujarat
Percentage of Households

Reasons	Year 1-2 (N=61)	Year 2-4 (N=111)	Year 4-6 (N=167)	Year 6-8 (N=164)	Year 8-10 (N=163)	Year 10-15 (N=164)	Year 15-20 (N=75)
Received Land and Compensation	28	11	6	4	5	4	1
Improved Access to Social Facilities	30	7	24	20	36	45	59
Better Living Conditions	21	25	13	23	18	18	20
Improved Housing	5	29	27	20	14	12	1
Good Incomes from Cultivation	16	28	30	34	28	21	19

Assessment of Impoverishment

Cernea's Impoverishment Risks and Reconstruction Model:

- Landlessness ✓
- Joblessness ✓
- Homelessness ✓
- Marginalization
- Increased Morbidity and Mortality
- Food Insecurity
- Loss of Access to Common Property ✓
- Social Disarticulation ✓

Note: ✓ denotes issues that were addressed

Landlessness

- Both in Ujjani and SSP no reported cases of landlessness among original 'oustees'.
- All reported received land as compensation
  - Ujjani: landlessness reported among second generation
- Ujjani and SSP Maharashtra – poor land quality reported
- But a reduction in the size of land owned/operated by the household

Changes in Land Size per Household Before and After Displacement - Ujjani

Land Size Class	Percentage of Household			
	Original Village		Present Location	
	Irrigated	Rain-fed	Irrigated	Rain-fed
<=5	34	22	82	86
<=6-10	22	22	12	11
<=11-20	24	26	4	1
<=21-30	8	14	1	1
<=31-50	7	10	1	1
> 50	5	6	0	0

Changes in Land Size per Household Before and After Displacement - SSP Gujarat

Land Size	Percentage of Household			
	Original Village		Present Location	
Class	Irrigated	Rain-fed	Irrigated	Rain-fed
<=5	37	36	92	92
<=6-10	37	24	6	5
<=11-20	20	25	2	2
<=21-30	4	9	0	1
<=31-50	2	6	0	0

Changes in Land Size per Household Before and After Displacement - SSP Maharashtra

Land Size	Percentage of Household			
	Original Village		Present Location	
Class	Irrigated	Rain-fed	Irrigated	Rain-fed
<=5	45	32	85	82
<=6-10	33	36	15	6
<=11-20	11	25	0	2
<=21-30	11	7	0	10

Occupational Changes

SSP:

- No open unemployment
- 33% household head changed their primary occupation
- 78% reported as current employment is more remunerative

Ujjani:

- No open unemployment
- Substantial number change to non-remunerative employment, especially those who were engaged in non-land-based livelihoods

Homelessness

- Insignificant in all locations
- Improved housing in SSP – Gujarat
- Poor housing in SSP – Maharashtra
- No significant improvement in Ujjani

Quality of Housing Before and After Displacement – SSP Gujarat

	Percentage of Households	
Nature of Housing	Original Village	Present Location
Homeless	2	1
Katcha	84	5
Semi-Pucca	7	15
Pucca	7	78
Modern House		2

Quality of Housing Before and After Displacement – SSP Maharashtra

	Percentage of Households	
Nature of Housing	Original Village	Present Location
Homeless		
Katcha	92	91
Semi-Pucca	7	5
Pucca	1	4
Modern House		

Quality of Housing Before and After Displacement – Ujjani

	Percentage of Households	
Nature of Housing	Original Village	Present Location
Homeless	2	1
Katcha	31	21
Semi-Pucca	31	48
Pucca	36	28
Modern House	0	1

- Access to Common Property
  - a problem in all three locations, especially for livestock grazing
  - curtailed access to forests not a major problem
- Social Disarticulation:
  - A major constraint in the immediate years of resettlement, especially in Ujjani due to conflicts with host communities
- Relatively Successful R&R in SSP – Gujarat
- The first time where such high standards of R&R had been applied to a project in India (WB 1998)
- This project has been the source of many improvements in R&R policies and implementation, especially in Gujarat

Comparison of Rehabilitation and Resettlement Policy in the Three SSP States

Article	NWDT Award	Madhya Pradesh	Gujarat	Maharashtra
Definition of oustee	a. Residing/trade at least for one year prior date of notification of land acquisition	Same as NWDT Cultivating land for 3 yrs	Same as NWDT	Same as NWDT
Family	Defined	Same as NWDT	Same as NWDT	Same as NWDT
Land Allotment	Minimum of 2 ha per family	Same SC/ST needs specified	Same as NWDT	Same as NWDT
Encroacher oustees	No land allotments	Treated as landed oustees subject to two conditions. i. Encroachment must be on or before 13.4.87. Allotment of agricultural land will be 1 ha. or 2 ha. ii) Encroachers will be entitled to get compensation for land under submergence.	i. Encroachers prior to 1 year of notification entitled for 2 ha. of land ii.Compensation for the balance encroached land as exgratia payment	2 ha of land and compensation as ex-gratia payment for the balance land encroached upto 31/3/78. Later encroachers will be treated as landless and will get 1 ha. agricultural land
Landless oustees	No land allotments	No land cash payment to agricultural labor and SC/ST	2 ha of land to landless agricultural labor only	1 ha land if oustee moves with the other
Rehab Grant	Rs. 750 per family	Small and marginal farmers, agricultural labor and SC/ST	Subsistence allowance NWDT award	Yes
Land Compensation	As per Land Acquisition Act	Same NWDT	Rs. 10,000 per ha	Rs.3,750-4,500 per ha

(Continued)

(Continued)

Article	NWDT Award	Madhya Pradesh	Gujarat	Maharashtra
Rehab grant and subsidies	R&R Grant of Rs. 750 per family Grant-in-aid of Rs. 500	R&R Grant-SC/ST, laborers, marginal farmers at Rs.11,000 each others at Rs.5,500	Generous: subsistence allowance. Grant to buy assets Housing grant	Subsistence allowance and other benefits as specified by NWDT
Other facilities	Transport, civic amenities	Yes	Yes	Yes

SSP - Investment in R&R per PAF by States
(as at 31/12/06)

Investment Details	Gujarat	Maharashtra	Madhya Pradesh	Total
Subsistence Allowance (Rs. - Crores)	2.07	0.3	1.91	4.28
Productive Assets (Rs. - Crores)	2.29	0.34	1.89	4.52
Resettlement Grants (Rs. - Crores)	0.59	0.05	0.03	0.67
Total	4.95	0.69	3.83	9.47
PAFs resettled	4,726	802	5,974	11,502
Investment per PAF (Rs)	10,474	8,603	6,411	8,233

Source: Estimated from Sardar Sarovar Punarvasavat Agency Data.

- On the implementation side, Gujarat developed a unique mechanism for acquiring replacement agricultural land, at market prices through Land Purchase Committees;
- Gujarat : Special agency for implementation and well-developed R&R units with central monitoring cells were established.

Concluding Remarks

- Results indicate that SSP (Gujarat) the oustees are not adversely affected to the extent claimed;
- Oustees do encounter initial stress and there is a fall in standard of living
- SSP - majority of oustees restored their livelihoods to the original level in 4-6 years;
- Data suggests that oustees in Madhya Pradesh and Maharashtra are worse-off than those in Gujarat;
- Hypotheses hold true partially in SSP;
- Ujjani ?
- Not to attempt to justify displacement;
- Forced displacement of population should be avoided where feasible.

National River Linking Project Analyses of Hydrological, Social and Ecological Issues

National Workshop: International Water Management Institute and Challenge Program for Water and Food Project on "Strategic Analysis of India's National River Linking Project"

October 9-10, 2007. Conference Room, NASC Complex, New Delhi, India

Agenda

Session I	Introduction Chair: Prof. M.S. Swaminathan	
09:00-09:30	1. Registration	
09:30-09:40	2. Welcome	Dr. Madar Samad
09:40-09:50	3. Workshop inauguration	
09:50-10:05	4. NRLP- A concept for meeting India's future water demand	Shri. Suresh Prabhu
10:05-10:20	5. NRLP- In the context of future global water demand	Dr. Peter G. McCornick
10:20-10:35	6. NRLP and perspectives on Indian irrigation: IWMI- CPWF project	Dr. Tushaar Shah
10:35-10:55	7. Inaugural speech	Prof. M.S. Swaminathan
10:55-11:00	8. Vote of thanks	Dr. Upali A. Amarasinghe
11:00-11:15	Tea/Coffee	
Session II	India's Water Future - Scenarios and Issues Chair: Prof. Y. K. Alagh	
11:15-13:00	1. Global water future - Scenarios and issues. Outlook from the Comprehensive Assessment of Agriculture	Dr. Peter G. McCornick
	2. India's water future - Scenarios and issues. Results from the analysis of phase I.	Dr. Upali A. Amarasinghe
	3. Water supply and demand in the Godavari (Polavaram)-Krishna (Vijayawada) link	Dr. Luna Bharati
	4. Discussion	
13:00:14:00	Lunch	

Session III	Hydrological feasibility of large-scale water transfers in India Chair: Eng. N.K. Bhandari	
14:00-15:30	1. What components of NRLP will work given the present trends of water demand?	Shri. Anil D. Mohile
	2. Hydrological and environmental issues of inter-basin water transfers in India: A case of Krishna River basins feasibility of some links- New perspectives	Dr. Vladimir Smakhtin
	3. In the midst of dam controversy: Objectives and criteria for assessing impacts of large dams in developing economies	Dr. Dinesh Kumar
	4. Discussion	
15:30:15:45	Tea/Coffee	
Session IV	Cost and benefits of irrigation water transfers Chair: Prof. Kanchan Chopra	
15:45-17:15	1. Public irrigation investments in India 1950-2000: An ex post facto economic analysis	Dr. Arlene Inocencio
	2. NRLP irrigation water transfers- benefits Case studies from Godavari-Krishna/ Ken-Betwa/ IGNP	Drs. Anik Bhaduri/ Upali A. Amarasinghe
	3. Impact of irrigation water transfers on gender and equity	Ms. Samyuktha Verma
	4. Discussion	
Session V	Future of rain-fed agriculture – Implication for NRLP water transfers Chair: Shri. B.M. Jha	
17:15-18:15	1. Rain-fed agriculture authority of India – Policy direction	Dr. J. S. Samra
	2. Rain-fed agriculture in India – Potential for productivity improvements	Dr. Bharat Sharma
	3. Discussion	

Day 2.		
Session VI	Contingencies that could justify large-scale water transfers Chair: Prof. B.G. Verghese	
09:30-11:30	1. To what extent can international trade contribute to manage India's future water demand?	Prof. Y. K. Alagh
	2. Biofuel as an energy source: Will India's irrigation demand need re-estimation?	Dr. C. de Fraiture
	3. Pricing out smalholder irrigation in South Asia?	Dr. Tushaar Shah
	4. Groundwater recharge opportunities with large water transfers- Case study from Godavari (Polavaram)-Krishna (Vijayawada link)	Drs. Bharat Sharma/ K.V.G.K. Rao/ Massuel Sylvain
	5. Potential in water harvesting in Indian river basins	Dr. Dinesh Kumar
	6. Discussion	
11:30-11:45	Tea/Coffee	
Session VII	Groundwater irrigation- Future directions for India Chair: Dr. J. S. Samra	
11:45-13:15	1. Groundwater irrigation in India- Future directions and policy issue	Shri. B.M Jha
	2. Decentralized recharge movements in India: Potential and issues	Dr. R. Sakthivadivel
	3. Real time co-managing of electricity and groundwater	Dr. Tushaar Shah
	4. Discussion	
13:15-14:15	Lunch	

Session VIII	Rehabilitation and resettlement management in large dam projects in India. The lessons for future water development projects Chair: Prof. V.S. Vyas	
14:15-15:30	1. Rehabilitation and resettlement issues in India	Dr. Ramaswamy Iyer
	2. Rehabilitation and resettlement issues Ken-Betwa Project	Dr. Vandana Shiva
	3. Assessment of rehabilitation and resettlement experiences in large dam projects: Case study results and lessons for the NRLP	Dr. Madar Samad
	4. Discussion	
Session IX	Transboundary conflicts Chair: Prof. Ramaswamy Iyer	
15:30-16:30	1. International experiences of transboundary water transfers: Lessons for NRLP	Dr. Francis Gikuchi/ Dr. Peter G. McCornick
	2. Linking rivers in the Ganges-Brahmaputra River basin: Exploring the transboundary effect	Dr. Anik Bhaduri
	3. Discussion	
16:30-16:45	Tea/Coffee	
Session X	Meeting future water demand through NRLP Chair: Dr. Peter G. McCornick	
16:45-18:00	1. Civil society perspectives of NRLP	Dr. Ashok Kosala
	2. The present status of inter-basin water transfers in India	Eng. N.K.Bhandari
	3. Phase III research plan- A water sector perspective plan for India	Dr. Upali A. Amarasinghe
	4. Meeting increasing water demand in India	Open discussion
18:00-18:10	Vote of thanks	Dr. Upali A. Amarasinghe

List of Participants

No.	Participant	Designation/Institute affliation
1.	Prof. M. S. Swaminathan	Chairman, M S Swaminathan Research Foundation, Chennai, Tamil Nadu.
2.	Mr. Suresh Prabhu	Chiar GWP-SA and Member of Parliament, Former Chiarman of the Task Force for Interlinking of Rivers, New Delhi.
3.	Prof. Kanchan Chopra	Director, Institute of Economic Growth, New Delhi.
4.	Prof. Y. K. Alagh	Former Union Minister of Science and Technology, Ahamadabad, Gujarat.
5.	Prof. V. S. Vyas	Professor Emeritus, Institute of Economic Growth, New Delhi.
6.	Mr. Anil D. Mohile	Former Chairman of Central Water Commission (CWC), New Delhi.
7.	Dr. J. S. Samra	Chief Executive Officer, National Rain-fed Area Authority, New Delhi.
8.	Mr. B. M. Jha	Chairman, Central Ground Water Development Board, New Delhi.
9.	Mr. A. D. Bhardwaj	Director General, National Water Development Agency (NWDA), New Delhi.
10.	Mr. N.K. Bhandari	Chief Engineer (HQ), NWDA, New Delhi.
11.	Mr. R.K. Jain	Director (Tech.), Ministry of Water Resources, New Delhi.
12.	Mr. Govind Sharma,	OSD, CAD & WU, Secretariat, Jaipur, Rajasthan.
13.	Mr. S. Sinha	Chief Engineer, Central Water Commission, New Delhi.
14.	Mr. R.K. Khanna	Chief Engineer (EMO), Central Water Commission (CWC), New Delhi.
15.	Dr. Alok Sikka	Director, ICAR-RCER & Basin Coordinator, Patna, Bihar.

16.	Dr. K. Vass	Director, Central Inland Fisheries Research Institute (CIFRI), Calcutta.
17.	Dr. P. K Katiha	Senior Scientist, Central Inland Fisheries Research Institute (CIFRI), Calcutta.
18.	Dr. R. Sakthivadivel	Formerly Principal Reseracher and Senior Fellow of IWMI, Chennai, Tamil Nadu.
19.	Mr. Ramaswamy R. Iyer	Visiting Professor, Centre for Policy Research, New Delhi.
20.	Prof. B. G. Verghese	Honorary Visiting Professor, Centre for Policy Research, New Delhi.
21.	Prof. K. C. Sivaramakrishnan	Honorary Visiting Professor, Centre for Policy Research, New Delhi.
22.	Prof. A. Narayanamoorthy	Director, Centre for Rural Development, School of Rural Studies, Alagappa University, Karaikudi, Tamil Nadu.
23.	Prof. Surender Kumar	Professor, The Energy and Resources Institute (TERI), New Delhi.
24.	Dr. Om. Prakash Singh	Lecturer, Banaras Hindu University, Varanesi, Uttar Pradesh.
25.	Dr. O. P. Singh,	Head of Department, Centre for Environmental Studies North-Eastern Hill University, Shillong, Meghalaya.
26.	Prof. R. P. S. Malik	Professor, Agricultural Economics Research Centre, University of Delhi, New Delhi.
27.	Dr. Abijeet Banerji	Reader, Dept. of Economics, Delhi School of Economics, New Delhi.
28.	Dr. P. S. Minhas	Assistant Director General (IWM), Indian Council of Agricultural Research, New Delhi.
29.	Dr. S.A. Kulkarni	Director - I, International Commission on Irrigation and Drainage (ICID), New Delhi.
30.	Mrs. Jancy Vijayan	Joint Director, International Commission on Irrigation and Drainage (ICID), New Delhi.
31.	Dr. Vijaya K. Labhsetwar	Director - II, International Commission on Irrigation and Drainage (ICID), New Delhi.
32.	Mr. Ravi Chopra	Director (Ex-Officio), People’s Science Institute, Deheradun.
33.	Dr. P. Sivaramakrishna	Director, SAKTI, Hyderabad, Andhra Pradesh.

34.	Dr. K. V. G. K. Rao	Indwa Technologies, Hyderabad, Andhra Pradesh.
35.	Mr. Ravindra Singh Chauhan	Project Director, Chhatrasal Sewa Sansthan (CSS), Hamipur, Uttar Pradesh.
36.	Mr. Arvind Ojha	Secretary, URMUL TRUST, Bikaner, Rajasthan.
37.	Mr. Himanshu Thakkar	Coordinator, South Asia Network on Dams, Rivers & People (SANDRP), New Delhi.
38.	Dr. Archana Chatterjee	Coordinator (Wetland Habitats), Freshwater and Wetlands Conservation Programme, WWF-India, New Delhi.
39.	Mr. Avinandan Taron	Doctoral Fellow, Centre for Ecological Economics and Natural Resources, Institute for Social and Economic Change, Bangalore.
40.	Mr. Shubhu Patwa	Bikaner Adult Education Association, Rajasthan.
41.	Mr. Ramuram	Farmer, Mankasar, Rajasthan.
42.	Mr. Ganeshram	Farmer, Ranjeetpura, Rajasthan.
43.	Mr. Chattarsingh	Farmer, Jaisalmer, Rajasthan.
44.	Dr. Peter G. McCornick	Principal Researcher, Director Asia Program, International Water Management Institute (IWMI), Colombo.
45.	Dr. Madar Samad	Principal Reseracher and Head, India Office, IWMI, Hyderabad.
46.	Dr. Vladimir Smakhtin	Principal Reseracher, IWMI, Colombo.
47.	Dr. Francis Gikuchi	Senior Researcher, IWMI and Theme Leader, Challamge Program for Water and Food, Colombo.
48.	Dr. Bharat Sharma	Senior Researcher and Head, IWMI New Delhi Office.
49.	Dr. Thushaar Shah	Principal Researcher, IWMI, Anand, India
50.	Dr. Upali Amarasinghe	Senior Researcher, IWMI, New Delhi.
51.	Dr. Luna Bharati	Researcher, IWMI, Colombo.
52.	Dr. Arlene Inocencio	Researcher, IWMI, Penang, Malaysia.
53.	Dr. Dinesh Kumar	Researcher and Head IWMI-TATA Water Policy Program, Hyderabad.
54.	Dr. Anik Bhaduri	Post Doctoral Fellow, IWMI, New Delhi.
55.	Mr. Lalith Dassanayake	Project Officer, Challenge Program for Water and Food, Colombo.

56.	Ms. Samyuktha Varma	Researcher, IWMI, Colombo.
57.	Mr. Nitin Bassi	Scientist, IWMI-TATA Water Policy Program, New Delhi.
58.	Mr. Amit Khare	Consultant, IWMI, New Delhi.
59.	Mr. B. K. Anand	Consultant, IWMI, New Delhi.
60.	Ms. Meena Bisht	Administrative Officer, IWMI, New Delhi.

Postal Address
P O Box 2075
Colombo
Sri Lanka

Location
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Telephone
+94-11-2880000

Fax
+94-11-2786854

E-mail
iwmi@cgiar.org

Website
http://www.iwmi.org

IWMI
International
Water Management
Institute

FUTURE™
HARVEST
IWMI is a Future Harvest Center
supported by the CGIAR

ISBN 978-92-9090-694-0