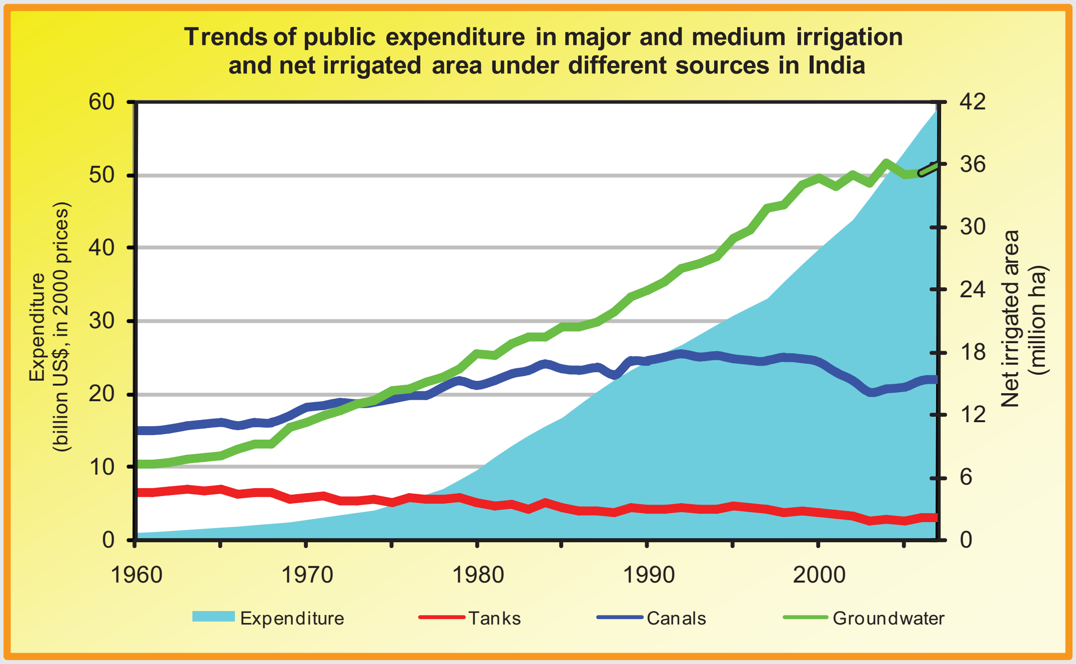
PROCEEDINGS

Strategic Analyses of the National River Linking Project (NRLP) of India
Series 5

Strategic Issues in Indian Irrigation


Trends of public expenditure in major and medium irrigation and net irrigated area under different sources in India

International
Water Management
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CGIAR Challenge Program on
WATER & FOOD

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Please direct inquiries and comments to: *iwmi-research-news@cgiar.org*

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Project

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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 research project was to inform the public and the policy planners of a balanced analysis of the benefits and costs of the different components of the National River Linking Project (NRLP). The project also conducted various research on experiences of past water development projects which can benefit new water transfers such as NRLP, and on major strategic issues in the Indian irrigation sector that require immediate attention.

The second national workshop of the project, held at the India Habitat Centre in New Delhi during April 8-9, presented the results of the studies on lessons that can be transferred from past to future water development projects, and strategic issues that require immediate attention for meeting India's increasing water demand.

This compendium of papers, the fifth and last of a series of publications under the IWMI-CPWF research project, includes the summary of keynote speeches and the deliberations in different sessions and the papers presented at the second national workshop.

Upali A. Amarasinghe
Project Leader
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Strategic Issues in Indian Irrigation: Overview of the Proceedings

Upali A. Amarasinghe and Stefanos Xenarios

Introduction

India's National River Linking Project (NRLP), if implemented in its entirety, will form a gigantic water grid that South Asia has never witnessed in the history of its water development. However, from the outset, the proposed NRLP plan was a bone of contention among the civil society, academia, environmental community, policy planners and politicians (Alagh et al. 2006). For opponents its economic benefits will not be sufficiently higher vis-à-vis its social and environmental cost. For its proponents, it is the savior of the pending water crisis in India (NWDA 2009). However, many of the discourses on NRLP lacked sufficient analytical rigor in assessing cost and benefits. And importantly there was very little attention to what determinants are ailing the existing surface irrigation systems leading to their poor performance, and what lessons can be learnt from these for new water development projects. Also, amidst the intense debate on social cost and benefits of the NRLP, many other important issues that require immediate attention for meeting India's water needs have been pushed into the background.

The research project, *The Strategic Analyses of National River Linking of India* of the International Water Management Institute (IWMI), Colombo, under the aegis of the *Challenge Program for Water and Food* (CPWF 2005), tried to address these twin challenges. It tried to fill the void created by the analytical rigor in the NRLP debate and to better informs the public on the pros and cons of the NRLP and the lessons to be learnt from the existing water supply systems. It also raises many strategic issues and challenges in Indian irrigation that require immediate attention.

The second national workshop of the NRLP research project, held at the India Habitat Centre in New Delhi, on April 8-9, 2009, mainly focused on strategic issues of Indian irrigation that require immediate attention. The issues highlighted at the workshop contribute to a cluster of short- to long-term strategies for a perspective plan for the Indian water sector. This paper provides an overview of the proceedings of the second workshop. It includes a description of the deliberations on:

- International and local perspectives on strategic issues facing the water sector, especially the irrigation sector.

- Planning new surface irrigation schemes for increasing benefits under changing dynamics of the Indian agriculture.
- The state of the irrigation of Tamil Nadu, one state that will benefit from the proposed NRLP water transfers. It shows trends and turning points of irrigation in the state, returns to past irrigation investments, and proposes investment options in the short and medium term for meeting increasing water demand.
- Lessons from past water resources development projects that are useful for planning new such projects.
- Prospects and constraints of demand management strategies in Indian irrigation.
- Potential and constraints of water productivity improvements in Indian agriculture.
- Supply augmentation through groundwater recharge and virtual water trade.

The papers in this volume are the fifth of a series of publications under the NRLP research project. The project conducted research in three phases. Research in Phase I, which assessed scenarios and issues of India's water futures, was published in NRLP Series 1, "India's Water Futures: Scenarios and Issues" (Amarasinghe et al. 2009).

Research in Phase II focused on cost and benefit issues related to the NRLP. Some, hydrological, social and ecological issues of the NRLP project were focused in the first national workshop and the proceedings were published in NRLP Series 2 (Amarasinghe and Sharma 2008).

Phase III research assessed potential contributions of various strategies for a water-sector perspective plan for India. Studies on "Promoting Demand Management Options in the Indian Irrigation Sector: Potentials, Problems and Prospects" were published in NRLP Series 3 (Saleth 2009), and the studies on "Water Productivity Improvements in Indian Agriculture: Potentials, Constraints and Prospects" were published in NRLP Series 4 (Kumar and Amarasinghe 2009).

The syntheses of studies on demand management and water productivity improvements were discussed in the 2nd national workshop. Additionally, supply augmentation through groundwater recharge and virtual water trade, and lessons from past water development projects on cost and time overruns, waterlogging and salinity, rehabilitation and resettlement of project-affected persons, are presented in this volume. Brief overviews of the deliberations in sessions 1 to 7 are followed next.

Session 1: Strategic Issues in Indian Irrigation

The major issues that the irrigation sector is facing were addressed by four guest speakers, Dr. Colin Charters, Director General, International Water Management Institute, Prof. M.S. Swaminathan, Chairman, M.S. Swaminathan Research Foundation, Dr. J.S. Samra, Chief Executive Officer, National Rainfed Area Authority and Dr. B.M. Jha, Director General, Central Groundwater Board of India.

Issues across the globe

Dr. Colin Charter's keynote speech focused on pressing global issues influencing water-food dimensions at present. Globally, many poor and hungry people live in regions where access to water is a constraint for increasing food production. In semiarid to arid tropics, about 800 million people are undernourished. Many river basins are already experiencing physical water scarcities while many others are facing economic water scarcities. Large numbers of river basins have low minimum river flows and consequently have high environmental stress. At present, more than one-third of the worlds' population live in river basins with high environmental water stress.

Yet, major demand drivers of water for food are also changing, resulting in rapidly increasing water needs. Consumption patterns are changing, mainly towards diets consisting of more non-cereals and animal products. Changing dietary patterns have significant implications on water demand. While a person needs about 2-5 liters/day, and a household needs 200-500 liters/day, it takes 2,000-5,000 liters/kg of evapotranspiration (ET) for producing grain to 5,000-15,000 liters/kg of ET, mainly from feed products, for producing animal products, such as meat, milk, etc..

The water demand, especially for blue water, of industrial and domestic sectors is increasing, and the demand for biofuel production will increase manifold in the next 20 to 30 years. A major part of biofuel water demand, especially in water-scarce regions, will have to be from irrigation (85% and 65% in India and China, respectivly versus 17% and 8% in the US and Brazil, respectively).

Climate change impacts on water availability are real, and they are already affecting some regions. Rainfall and runoff have decreased significantly in some regions, while the reduction in runoff is comparatively higher than that of rainfall. Implications of such reduction on already water-stressed basins, especially in developing countries, could be catastrophic.

In fact, many countries are facing water crises. But these crises can be averted if the countries do things differently. Some high potential strategies for water-scarce countries include increasing water productivity, turning wastewater to a valuable resource and increasing virtual water trade with few trade barriers. Additionally, various types of storage options, including large to small dams to subsurface storage, clearly need rethinking.

Many countries with low per capita storage require increasing storage to cope with droughts and impacts due to climate change. These countries need large investments, a message that needs to be communicated to politicians and policymakers with added significance. Hydropower industry also needs large dams. But the dams need to be built and managed efficiently for irrigation and for other multiple water uses while reducing environmental damage and ensuring minimum river flows. There are many other options to large dams. Medium-scale reservoirs, village ponds, groundwater recharge and water harvesting can augment water significantly. However, all options need to be evaluated for assessing potential gains and losses under different conditions.

Reforming water governance is essential for demand management to be successful. While protecting the poor, water rights, valuation of water and pricing, water markets, policies and institutional reforms, equitable and gender sensitive management systems need to be in place for effective functioning of supply and demand management systems.

Issues in India

Prof. M. S. Swaminathan highlighted strategic issues of irrigation in India. He noted that water planning for supply augmentation for a national water security system requires integrating of five sources of water: rainwater, river water, groundwater, wastewater and seawater.

- Rainwater is the greatest asset at hand. The most important step for supply augmentation in India today is rainwater harvesting. The national rural employment guarantee program (NREGP) plays a major role in water harvesting and watershed development programs. These programs can be made more effective by empowering the Panchayat Raj institutions, which are responsible for implementing NREGP, to use the unskilled labor of the poor people as productively as possible. Rewarding these institutions/NREGP for conducting better programs could be an incentive for contributing to a water security system.
- River water, a part of the river linking project, is also important. However, there are many conflicts in water sharing between neighboring nations and between states at present. India requires many non-judiciary conflict resolution organizations, such as the Key-Stone centre in the Colorado River in the USA. These centers can resolve many conflicts and have win-win situations for all parties in the conflict without relying on long-delayed judicial processes.
- Groundwater is the most dominant water use at present. It contributes most to both receding and rising water tables in many regions. Managing this resource is the most important short- to long-term water management challenge.
- Wastewater recycling is gradually increasing in metropolitan areas. This is an important source not only for raising fodder and other crops but for breeding fish. Industries can be made to give back the water by proper methods of recycling.
- Seawater is useful for agro-aqua-farming, including agroforestry and aquaculture. Given India’s 7,500 km shore line, this aspect of using seawater productively requires more consideration.

Linking of rivers could be one option for easing the water stress in some locations where the links are economically viable and environmentally sustainable. However, as of now, the Himalayan component presents a large number of political problems and may not be feasible in the short term. The peninsular links are feasible to the extent that the political control of designing, planning and implementing is within India. The new government could takes up these as priority issues.

While supply-side solutions are essential, demand management strategies also have significant potential to address water problems in many locations. Policy formulation for effective functioning of demand management strategies requires increased emphasis. Within this, it is important to increase more crops and more income from water, and create more opportunities in rain-fed areas. Some experiments, under the Farmer Participatory Program in rain-fed areas show yield increase in the range of 200-300%. These can reduce the additional demand for large surface storages.

According to Dr. Samra, rain-fed agriculture has a great potential for improving the livelihoods of the poor. Data indicate that 78% of the Indian agriculture is linked to markets. The other 22% is subsistence agriculture, mainly in the rain-fed areas. Many of the poor also live in rain-fed areas, but most of the virtual water trade is occurring from low- to high-rainfall areas. This is a paradoxical situation of virtual water trade, in particular for India. Reversing the trends of virtual water trade within the country could solve many water and poverty problems. Most of the water-intensive crops, such as rice, sugarcane, banana and aquaculture should, as far as possible, be in high rainfall areas and be exported to low-rainfall areas. These forms of high-value agriculture can constitute an attractive proposition for the eastern regions, which are reeling with a high incidence of rural poverty.

Dr. Jha highlighted the criticality of groundwater irrigation in India's food and livelihood security. Groundwater is the source for more than 60% of the irrigation at present. But many regions are fast depleting their resources due to overabstraction. The Government of India has a national master plan for increasing groundwater recharge, which includes recharging from millions of dug wells dotting the rural landscape in India.

Session 2: Benefits of Irrigation Water Transfers

The changing face of irrigation (Paper 2 by Tushaar Shah), and the financial benefit-cost of proposed irrigation water transfers in the NRLP (Paper 3 by Amarasinghe and Srinivasulu) were the foci of this session.

According to Shah, the face of Indian irrigation is rapidly changing. India has spent over Rs 1,000 billion ($22 billion in 2000 prices) on surface irrigation since 1991. But net area under surface irrigation has declined by 24%. Since 1970, Tamil Nadu and Andhra Pradesh, two major water-recipient states of the NRLP, have spent over $5 billion in canal irrigation, but have lost close to 500,000 ha of net irrigated area under major/medium schemes. Since 1990, net area under groundwater irrigation area has increased by 26%. This was mainly due to private investments. Groundwater irrigation is widespread, both in and outside the canal command have areas, although overexploitation is threatening irrigated agriculture in many regions. Many factors contribute to this changing face of irrigation. They include

- pressure of decreasing landholding sizes and large number of smallholders,
- increasing demand for year-round on-demand water supply for increasing income from small landholdings,
- inefficient institutions providing irrigation services and unreliable water supply in canal irrigation,
- differences of existing and proposed conditions supporting surface irrigation, including the nature of both the state and agrarian society,
- changes in agricultural demography, and
- adoption of new irrigation technology.

These factors, thus pose a major question on the viability of large surface irrigation systems such as those proposed in the NRLP.

Amarasinghe and Srinivasulu (Paper 3 in this volume) assessed the financial viability of water transfers in the peninsular links in the proposed NRLP. This study shows that proposed surface irrigation through the river linking program can be financially viable if the planners appreciate the changing face of irrigation and then adapt to these changes. In order to avoid the same fate and issues as that facing surface irrigation at present, many factors need rethinking in the current river linking proposal. Two of the major factors of influence include that

- the proposed cropping patterns will require high-value crops, and those that farmers prefer. This is especially important given the low landholding sizes in these systems.
- new water transfers should be used as far as possible to cultivate new or existing irrigation. A large part of the proposed command areas is already irrigated from groundwater. The return flows from new irrigation should help these command areas as recharge. Farmers would prefer groundwater irrigation to surface water irrigation due to already existing investments on pumps and other infrastructure and to the reliability of groundwater.

Although, many individual links under the NRLP peninsular component seem financially unviable, a set of interdependent links could be financially viable under the above conditions. But financial benefits and cost could vary if financial losses due to reducing river flows, submerging land, waterlogging, etc., and financial benefits due to increased groundwater irrigation are included.

The discussion on the above issues, led by Dr. Ashok Gulati of the International Food Policy Institute and by Dr. Madar Samad of IWMI, indicated the need for unbundling surface irrigation to have separate institutions as in other development sectors. Although, in general, participatory irrigation management (PIM) did not have much success, there are a few successful systems in different states. So, it is important to find what works for different states and different irrigation systems. If PIM does not work at the system level, then explore different institutions at the storage, main canals and the distributary network with the multinationals, and the domestic and private sectors. Creating markets with policies can facilitate effective functioning of these institutions with increasing transparency, accountability, cost efficiency, inclusiveness and sustainability.

Also, there is a significant difference in benefits between canal irrigation systems and surface water systems. Canal irrigation systems provide water for food production whereas surface water systems provide a large quantity of drinking water supply for urban areas, generate hydropower benefits, pump irrigation from rivers due to releases from reservoirs, recharge groundwater and benefit the environment. These benefits, along with food security at the household, regional and national level should be part of a domain for analyzing financial and economic cost benefit of surface water systems. However, it is also important to include the cost to ecosystem services system for demarcating the boundaries of benefits-cost of surface water systems.

Session 3: State of the Irrigation in Tamil Nadu: Trends, Turning Points and Future Options

Tamil Nadu, a major recipient state of the water transfers in the NRLP, had significant changes in irrigation in the recent past. Trends and turning points of irrigation (Paper 4 in this volume) and policy interface for improving declining performance in surface irrigation (Paper 5 in this volume) in Tamil Nadu were the foci of this session.

Irrigation is a major driver of agricultural growth, which is intrinsically related to the economic growth in Tamil Nadu. However, in spite of major investments in the irrigation sector, net surface water irrigated area has declined over the last three decades. The total investment in major/medium irrigation has increased by $730 million (2000 prices) between 1970 and 2000, but the net canal irrigated area has declined by 85,000 ha or 9%. Total investment in tank irrigation in the same period was over $430 million, but net minor irrigated area has declined by 450,000 ha or about 50%. However, with private investment, net groundwater irrigated area has increased by about 500,000 ha. Although the contribution of groundwater has increased substantially, many regions in the state are facing acute groundwater depletion. In fact, 85% of the groundwater resources in the state are already withdrawn at present.

To overcome water woes, Tamil Nadu requires sharper policy focus on short- to medium-term irrigation investments. Some policy recommendations include:

- recharging groundwater in intensive well irrigation regions,
- conserving soil and water in tank irrigation regions,
- combining five to six micro-watersheds to form macro-meso watersheds within a zone of influence of 400 m,
- converting tanks, with less than 40% supply capacity, to percolation tanks and increase groundwater irrigation in the command area by introducing one well per 2 ha in well-only irrigation situation; one well per 4 ha in well-cum-tank irrigation situation, and one well per 10 ha in tank-only irrigated areas,
- increasing wells in surface water irrigation systems and reworking system operation plans,
- increasing investment in watercourse improvements in major reservoir systems,
- increasing investments in main systems in tank irrigation systems, and
- investing in secondary and main system management for increasing demand management.

The discussion of the above issues, led by Eng. A.D. Mohile, former Chairman of the Central Water Commission of India, noted that water transfers of the NRLP can be used within a network of interlinking of rivers within the state, although water received through NRLP may be too low to address all water problems in the state. Moreover, successful implementation of the above recommendations, however, requires a comprehensive water accounting analysis assessing the impact of increase in groundwater in the canal and tank irrigation commands.

Session 4: Lessons from Past Water Transfer Projects

Many existing water development projects, which India has implemented in recent decades, have a plethora of issues that can benefit planning and implementing new water transfer projects. In this session, Thalati and Shah (Paper 6) focused on project implementation issues in the Sarda-Sarovar project; Sharma et al. (Paper 7) addressed waterlogging and salinization issues in the Indira Gandhi Nehar Paryojana (IGNP) project in Rajasthan, and Samad et al. (Paper 8) highlighted resettlement and rehabilitation issues in the Sarda-Sarovar and Ujjini projects.

The Sarda-Sarovar project suffers from many issues due to inadequate details in the planning and implementation (Paper 6). Hydrologically, it suffers from lower inflow to the reservoir than expected. The project planners had not envisaged large-scale groundwater abstractions in the upstream of the reservoir. Hence, the inflow to the reservoir is already 17-30% lower than planned, and will further reduce with increasing upstream development. Significant cost and time overruns were also major issues. The Government of Gujarat has already overspent more than Rs 130 billion (in 1987/88 prices) in the construction of the project. Yet, only 0.1 million ha (Mha) of the 1.8 Mha of planned area are irrigated; only 200 MW of the planned 1,460 MW hydropower generation are realized; and only 35 and 1,500 of the 135 and 8,215 towns and cities, respectively, have received water supply to date. If the project is to be completed as planned it requires at least another Rs 2,000 billion. The failure of the planned institutional model largely contributed time and cost overruns. The expectation that farmers and water user associations would voluntarily provide land and also build watercourses and field channels, has never materialized. Instead, farmers divert a significant part of the water to far-away lands from the main and branch canals by lifting to upland areas and siphoning to lowland areas through underground pipes. Such innovations are not common in surface irrigation projects, but can impact significantly in reducing problems related to land acquisition for distributaries and watercourses, and water distribution to tail-end areas in the project.

A large part of IGNP projects suffers from waterlogging and salinity (Paper 7). A considerable lag period between water availability and water utilization in the command areas was a major cause for waterlogging. For example, in Phase II of the IGNP project, the available water supply is adequate to irrigate 0.925 million ha of croplands, but the distributary network is sufficient to irrigate only 0.144 million ha. Moreover, inadequate attention to the existing hard pan, which is only less than 10 meters from the surface, exacerbated the situation. In fact, in the IGNP, the hard pan with less than 10 m depth covers more than 33% of the flow irrigated area and 76% of the lift irrigated area. Inadequate drainage was a major issue in the IGNP.

Resettlement and rehabilitation are major issues facing implementers of any water development project. The studies on Sarda-Sarovar and Ujjini projects however show that there is an initial distress and fall of standard of living. But many of the displaced persons have restored their livelihoods to the original level in 4-6 years, although the level of restoration and benefits vary spatially. Those displaced in Maharashtra and Madya Pradesh in the Sarda-Sarovar are worse-off than those in Gujarat.

The major conclusions from the discussion of this session, led by Mr. Himanshu Thakkar were:

- Hydrological modeling should incorporate the groundwater irrigation already taking place and expected to come up in the future in the command area and in the upstream of reservoirs, and should assess drainage requirements with regard to the existing hydrogeological conditions and the command area development.
- Be cognizant of the existing modes of water delivery systems at the watercourses, and the farm and field levels in planning new systems .
- The pump and pipe system of water delivery could reduce water and land wastage through watercourses and field channels.
- Piped water delivery system, possibly at or below the distributary canals, can also increase reliability and reduce wastage. But such systems should have a mechanism in place not to deprive water to the tail enders to increase the equity.
- Create institutions for appropriate water delivery management at the branch/distributary canal level.
- Prepare proper command area development plans, optimum water delivery plans and adequate drainage structures.

- Develop distributaries, watercourse and field-level distribution systems quickly to reduce the gap of water availability for irrigation and water utilization, thereby increasing consumptive water use and reducing waterlogging.
- There should be active engagement to reduce not only the initial risk but also the impact of impoverishments after resettlement.

Session 5: Meeting Increasing Water Demand: Potential from Demand Management Strategies

The growing gap between the demand and supply in Indian irrigation is a serious concern for policy planners. While, supply-side solutions based on new augmentation, such as NRLP, are essential in some contexts, they cannot be the exclusive basis for irrigation sector strategies. Many demand management strategies will help reduce the gap. Paper 9 presented the synthesis of six studies of various demand management strategies in the Indian irrigation sector (Saleth 2009). These strategies include water pricing, formal and informal water markets, water rights and entitlement systems, energy-based water regulations such as power tariff and supply manipulations, water saving technologies such as drip and sprinklers, crop choices and farm practices, and user- and community-based organizations.

The major focus of these studies was to asses the present status of these options in the irrigation management strategy in India. It includes the extent of their application, their effectiveness in influencing water use decisions at the farm level, presence of policies in promoting them at the national and state levels, cases of success and best practices in demand management, and what lessons there are for policy in upscaling them. What are the bottlenecks and constraints for promoting them on a wider scale, particularly within the irrigation sector? What are the present potentials and future prospects for these options as an effective means for improving water use efficiency and water saving, which are sufficient enough to expand irrigation or to reallocate water to nonagricultural uses and sectors?

The focus and coverage show that some demand management options are context-specific. For instance, water pricing as a tool is largely applicable to canal regions, whereas the options involving energy regulations—involving both supply and price manipulations—is largely applicable in groundwater irrigation. The latter may also be relevant in canal regions to the extent where water lifting is involved. Water markets and water saving technologies also occur predominantly in the groundwater irrigation regions. But, the options involving water rights and user organizations are relevant in both canal and groundwater regions. Similarly, some of the options have more direct and immediate impacts on water demand, while others have an indirect and gradual effect and, that too, depending on a host of other factors. For instance, water rights and water saving technologies have a more direct effect on water demand, and the options involving user organizations and energy regulations have only an indirect effect.

The demand management options also differ considerably in terms of the scope for adoption and implementation, especially from a political-economy perspective. Among the options, water rights system is the most difficult one followed by water pricing reforms and energy regulations, but those involving water markets and user organizations are relatively easier to adopt, though their implementation can still remain difficult. Water saving technologies, though politically benign and not controversial, still require favorable cropping systems and effective credit and investment policies. The differences in their application context, political feasibility and the gestation period of impact are very important and should be understood because such factors will determine the relative scale of application and the overall impact of the demand management options.

As for the influence, some of the options can have immediate effects and some others have the potential to influence water allocation and use. However, these effects are rather too meager to have an impact on the magnitude needed for generating a major change in water savings and allocation. The two central problems limiting the impacts of demand management are their limited geographic coverage and operational effectiveness. Concerted policies are also lacking in really exploiting their demand management roles. All these options are pursued as if they are separate and essentially in an institutional vacuum because the necessary supporting institutions are either missing or dysfunctional in most contexts.

However, a concerted policy for demand management in irrigation in India is conspicuous for its absence both at the national and state levels. Instead, what is being witnessed is a casual and ad hoc constellation of several uncoordinated efforts in promoting the demand management options. In most cases, these options are pursued lesser for their demand management objectives than for their other goals such as cost recovery and management decentralization. Even here, the policy focus is confined only to a few options, such as pricing, user organizations, energy regulations and, to a limited extent, water saving technologies. Although several policy documents and legal provisions clearly imply a water rights system, there are no explicit government policies either as to its formal existence or to its implementation, except for the recognition of the need for volumetric allocation and consumption-based water pricing. This is also true for water markets, though their existence and operation across the country are well documented. Considering the critical importance of water rights and water markets for their direct effects on demand management and their indirect effects in strengthening other demand management options, it is important that they are formally recognized and treated as the central components of a demand management strategy.

Although the effectiveness of demand management options are constrained by several institutional, technical and financial factors, the lack of a well-articulated policy is the major bottleneck for implementing water demand management both at the national and state levels. Such a policy provides the basis for the much-needed financial and political commitments for implementing effective demand management programs. An effective demand management strategy can both expand irrigation and release water for other productive uses even at the current level of water use. Therefore, it is logical to divert at least part of the investments that are currently going into new supply development.

Session 6: Meeting Increasing Water Demand: Potential from Water Productivity Improvements

The agriculture sector in India is in direct conflict with other sectors of water economy, and the environment. The common features of agriculture in some regions are excessive withdrawal of groundwater and excessive diversion of water from rivers, causing environmental water stress. The scope for augmenting the utilizable water resources in these regions is extremely limited. While there are many regions in India where water resources are abundant, these regions offer limited potential for increasing agricultural production due to the limitations imposed by land and ecological constraints. Moreover, productivity of water use is very low in India for major crops in terms of the amount of biomass produced per unit of water depleted in crop production. So, improving water productivity (WP) in agriculture, wherever possible, holds the key to not only sustaining agricultural production and rural livelihoods but also making more water available for other sectors including the environment. Paper 10 presents a synthesis of several studies covering various aspects of WP and their potential improvements in India (Kumar and Amarasinghe 2009). These studies include quality and reliability of water supply affecting WP, strategies of WP improvements at different scales, potential WP productivity improvements in food grains, WP in dairying and in different agricultural systems including multiple uses, and taking the concept of WP beyond more crop per drop to more value per drop and its implications for the agriculture sector in India.

Improving water productivity in agriculture can bring about many positive outcomes. In some regions, WP improvement would result in increased crop production with no increase in consumptive use of water, while in some others it would result in reduced use of surface water or groundwater draft. Both outcomes would protect the environment. On the other hand, there are certain regions in India where yields are very poor as the crops are purely rain-fed in spite of having a sufficient amount of unutilized water resources. Augmenting water resources and increasing irrigation in such regions can result in enhanced yield and income returns, as well as improvements in water productivity. Such strategies have the potential to reduce poverty in these regions.

Opportunities

There are several opportunities for improving the water productivity of crops in India. They include:

- providing full irrigation to meet the full crop evapotranspirative demand or providing supplemental irrigation in critical periods of crop growth for the rain-fed crops for increasing the crop yield,
- replacing long-duration food crops with higher water use efficiency by short-duration ones with low efficiency; and growing crops in regions where their yields are higher due to climatic advantages (high solar radiation and temperature, for instance), better soil-nutrient regimes or lower ET demand,
- Practicing deficit irrigation in areas where yield is large and consumptive water use is very high,
- improving the quality and reliability of irrigation water,
- managing irrigation for certain crops by controlling or increasing allocation to the said crops,
- adopting high-yielding varieties without increasing the crop consumptive use,
- Bridging the yield gap by providing optimal dosage of nutrients such as artificial irrigation and fertilizing; and improving farming systems with changes in crop and livestock compositions.

Food crops such as paddy and wheat dominate cropping patterns in many irrigated districts in eastern India. The yields of these food crops are significantly lower than the maximum attainable under similar conditions. There are 202 districts in the country which fall under the category of medium consumptive use of water for irrigated crops (300-425 mm), but with high yield gaps. Improved agronomic inputs (high-yielding varieties and better use of fertilizers and pesticides) can significantly raise the yields. This will have a positive impact on water productivity though it is not a concern for farmers in this water-abundant region of India. While there are districts in central India, where better use of fertilizers would help enhance crop yields, these areas also require an optimum dosage of irrigation also to achieve higher crop yields.

There are many irrigated areas in western India with large potential for water productivity improvements through water delivery control, improving quality and reliability of irrigation water supplies, and use of micro-irrigation systems. Water productivity in irrigated crops could be enhanced significantly through deficit consumptive water use through deficit irrigation. This could be a key strategy in water delivery control in 251 districts. These districts already have a very high yield per unit of land and receive intensive irrigation.

Most of India's "so called" rain-fed areas are in central India and the peninsular region. There are 208 districts with low (below 300 mm) average consumptive use of water for food grain production. These districts have large areas under rain-fed course grains like pulses such as green gram and black gram. These crops give very low grain yields, resulting in low WP. Supplementing full irrigation can boost both yield and WP significantly in the rain-fed areas of these districts.

Constraints

In spite of large opportunities, there are many constraints for increasing water productivity too. They include:

- constraints induced by land availability,
- food security concerns and regional economic growth. Cereals such as rice and wheat are important for food security of India but have low water efficiency, compared to cash crops such as cotton, castor and groundnut which have high water use efficiency,
- existing institutional and policy frameworks in improving water productivity for irrigated crops. For instance, in many situations, improvement in water productivity in kg/ET or Rs/ET does not convert into better returns for the farmers due to inefficient pricing of water and electricity. The policy constraints concern the pricing of water used in canal irrigation and electricity used in well irrigation, whereas the institutional constraint comes from the lack of well-defined water rights for both surface water and groundwater. Both aspects leave minimum incentives for farmers to invest in measures for improving crop water productivity as such measures do not lead to improved income in most situations,
- lack of knowledge and wherewithal to adopt technologies and practices to improve water productivity in agriculture, especially in the communities dependent on rain-fed crops,
- lack of credit required to invest in water harvesting systems for supplementary irrigation for rain-fed crops and economic viability issues.

In a nutshell, while there seem to be great opportunities for improving water productivity in agriculture the extent to which these can be achieved depends on the scale at which the above-mentioned constraints operate.

Some of the policy and institutional interventions are as follows:

- improving the quality of irrigation water supplies from canal systems, including the provision for intermediate storage systems like the *diggies* in Rajasthan,
- improving the quality of power supply in agriculture in regions that have intensive groundwater irrigation and improving electricity infrastructure in rural areas of eastern India,
- providing targeted subsidies for micro-irrigation systems in regions where their use results in major social benefits,
- investing in rainwater harvesting for supplementary irrigation in rain-fed districts, and
- rainwater harvesting and irrigation infrastructure for supplemental or full irrigation would significantly enhance crop yields in many, and water productivity in some, rain-fed areas. This would be a medium-term measure.

Session 7: Meeting Increasing Water Demand: Augmenting Water Supply through Artificial Groundwater Recharge

Shah (Paper 11) and Sunderrajan et al. (Paper 12) assessed opportunities and constraints of the groundwater recharge master plan and recharge through dug-well programs in India.

For many centuries, surface storages and gravity flow have been the main source of irrigation for Indian agriculture. However, over the last four decades, while surface water irrigation has been gradually declining, groundwater irrigation through small private tube wells has been flourishing. Groundwater is contributing to about two-thirds of the gross irrigated area, but this contribution could be even more if all the conjunctive water use areas are also accounted for. Contrary to what most claim, groundwater irrigation has spread everywhere, even outside canal command areas where recharge from surface return-flows could not have reached. As a result of this boom, a significant part of India's agricultural production and rural livelihoods depend on groundwater irrigation. This boom is also a threat due to overexploitation. Thus sustaining groundwater irrigation is essential for a country like India, because groundwater irrigation, a) gives large spatially distributed social benefits by spreading to vast rural areas that surface irrigation generally has not reached and cannot reach, especially benefiting the large number of smallholders in Indian agriculture, b) is more efficient in irrigating crops, thus allowing better application of agricultural inputs and crop intensification and diversification, resulting in higher yields and an income per unit land than in canal command areas, c) is a better mechanism for drought proofing, and enhances the importance of mitigating impacts due to climate change. For sustainable groundwater irrigation, India needs to make more artificial recharge in many locations and better managements of aquifer storages.

India's National Master Plan for Groundwater Recharge proposes augmenting the water resources annually by another 38 billion m^3. The program, costing Rs 2,450 billion ($6 billion at the January 2008 exchange rate), proposes many recharge structures including percolation tanks, check dams, cement plugs and *nala* bunds, gabian structures akin to check dams, village tanks modified to serve as recharge tanks by desilting and fitting them with cutoff trench and a waste-weir, recharge shaft, that is a trench backfilled with boulder and gravel, subsurface dykes or groundwater dams, dried-up or disused dug wells; injection wells in alluvial aquifers overexploited by tube-well pumpage and roof-water harvesting structures especially for urban settlements, etc. Paper 11 assessed the shortcomings of the master plan and how best that can be implemented in the future to reach its potential benefits. Shah contends that the master plan should

1. Be based more on demand-side principles—that it should recharge more in areas where groundwater use is heavy and depletion is critical, than the supply-side principle—that it locates most recharge structures where uncommitted surplus water is high and aquifers are roomy.
2. Optimize allocation of financial resources by allocating according to the degree of depletion of resources. These are the areas where groundwater demand is high and supply is inadequate. Else, many regions where groundwater demand is less and water depletion is low could get a substantial amount of resources.
3. Have a clearly defined pathway of implementation, indicating the role of different agencies in supervising implementation and monitoring the performance.
4. Consider the sustainability of the recharge structures, because most of the recharge structures are proposed on government land and common property.
5. Seek active participation of local stakeholder participation, i.e., individual users or local communities, for not only on maintenance but also on construction of these structures. Stakeholders' participation is essential for maintenance of these structures.
6. Understand and respect the contextual specificities of groundwater depletion. It should assess the drivers behind the boom of groundwater extraction. The plan should accept the fact the surface water storage will not respond to the socio-ecology of groundwater boom in India, and groundwater recharge should not be the last resort for storing surface runoff.
7. Harmonize priorities with stakeholders' needs. While the plan proposes to locate structures where they can recharge to the maximum, the stakeholders prefer to have them located where the demand is maximum.

Shah's study proposes an alternative plan by recharging dug wells scattered in hard-rock areas, resulting in augmenting more groundwater resources than the master plan does. This alternative plan also responds better to the seven considerations mentioned above.

The study by Sunderrajan et al. assessed the prospects and constraints for recharging groundwater through dug wells. Using a survey of 767 dug-well owning farmers in seven districts in India, this paper shows that there is indeed an enormous hydrological prospect for recharging groundwater in hard-rock areas through dug wells. Although there are some reservations by farmers, they generally agree that recharge through dug wells increases water availability, especially during the dry season. The reservation is mainly on the fact that they can use only a small fraction (30%) of the recharge in their farms, but the farmers agree that there are common benefits from this recharge. This paper suggests assessing different models managing dug-well recharge, including applying a group of ten farms for recharge; the subsidy for constructing structures is transferred to farmers in April or May, as most of the farmers unanimously prefer; promote local businesses around recharge structures, such as to harness the experience of well drillers, who also operate during the same summer months.

Virtual Water Trade

The virtual water trade concept suggest that water-rich countries should produce and export water-intensive commodities (which indirectly carry embedded water needed for producing them) to water-scarce countries, thereby enabling the latter to divert their precious water resources to alternative, higher-productivity uses. The study by Verma et al. (2008) quantifies and critically analyzes interstate virtual water flows in India in the context of a large interbasin transfer plan of the Government of India.

This analysis shows that the amount of virtual water traded between states is more or less equivalent to the water transfers of 178 Bm^3 proposed in the NRLP. Much of the water trade is from water-stressed to water-surplus states at present. In fact, the existing virtual water trade between states exacerbates water scarcities in some states. The existing pattern of interstate virtual water trade is influenced by non-water factors such as “per capita gross cropped area” and “access to secured markets.”

This study suggests that in order to comprehensively understand virtual water trade, non-water factors of production need to be taken into consideration. This includes some changes to food procurement and input subsidy policies.

Conclusion

Increasing reliance of groundwater and declining area under surface irrigation are the prominent recent trends in Indian irrigation. Given this changing face of irrigation, many issues in groundwater and surface irrigation require immediate attention.

Recharging groundwater is an immediate requirement for sustaining the present groundwater economy and for distributing irrigation benefits to a larger part of the population. Empowering local institutions on watershed development programs, combining several micro-watersheds within a radius of 400 m with meso-watersheds for development, recharging groundwater through millions of dug wells, converting small tanks to percolation ponds, increasing groundwater irrigation tank commands, and changing irrigation scheduling in canal commands to increase conjunctive water use are some measures for sustaining groundwater irrigation.

Water productivity improvements could significantly reduce the requirement for additional water development. Increasing crop yield by providing supplemental irrigation in major rain-fed districts with low consumptive water use (below 325 mm), reducing the yield gap in many irrigated areas without increasing the total consumptive water use (325-475 mm), deficit irrigation to provide deficit consumptive water use in irrigation districts with large consumptive water use (more than 450 mm), and increasing multiple water uses in water-abundant rain-fed areas are some strategies towards increasing water productivity in agriculture.

Demand management strategies can reduce the widening gap between supply and needs. If implemented with stronger policy backing, water pricing, formal and informal water markets, water rights and entitlement systems, energy-based water regulations, water saving technologies, and user and community-based organizations would go a long way towards reducing this gap.

Virtual water trade can ease the stress in water-scarce regions, and provide livelihood opportunities and reduce poverty in the eastern regions. However, proper policy and institutional and infrastructural facilities are necessary to change cropping patterns in different regions to make virtual water a win-win proposition for all regions.

New surface water development projects, including water transfers between rivers as in the NRLP, may become necessary for meeting water demand in some regions. However, planning of such projects should give due consideration to local hydrological, economic and social trends and conditions. Planners should introduce innovative water distribution networks to reduce water and land wastages in watercourses and field channels. They should also set up water allocation institutions that are transparent and accountable to the end users. Proper markets and policies are preconditions for effective functioning of these institutions.

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Reform or Morph?
Unlocking Value in Asian Irrigation[1]

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"The development of irrigation has outrun its administration"
Col. W. Greathed, Chief Engineer, Upper Ganga Canal, 1869

Asian Irrigation in Transition

Gravity-flow irrigation has dominated irrigated agriculture in Asia for millennia. Until European colonial powers began constructing large centrally managed irrigation systems in the nineteenth century and later, much irrigation in Asia, small-scale and organized irrigation, existed around communities. During the colonial era, European initiatives in building large irrigation projects under centralized management marked a watershed in Asia's irrigation history; and until the 1940s, much new irrigation development took place under colonial governments which viewed irrigation as a way to blend "interests of charity and the interests of commerce." In India, the British levied enhanced taxes from irrigated land; in Taiwan and China, Japanese sought enhanced rice supplies by investing in irrigation. With the end of colonialism, the tradition of centralized irrigation-building and management has been continued by national and subnational governments for food security and poverty reduction with significant support from multilateral international financial agencies. However, poor management and performance of public irrigation systems were concerns throughout the colonial era; and these concerns have multiplied manyfold in the postcolonial Asia.

During recent decades, surface irrigation has been in decline in many parts of Asia. Public irrigation systems have tended to be underutilized and overcapitalized, and typically serve only a fraction of the designed command. With aging, irrigation commands have been sinking under the weight of their managerial, economic and environmental problems. In the Indian subcontinent by far the largest areas under surface irrigation in Asia, small surface structures, notably tanks in southern India and Rajasthan, *karezes* in Pakistan and Iran, *kuhls* in the Himalayas, and *ahar-pyne* systems in southern Bihar had been losing irrigated areas since the 1950s. But during the 1990s, even large public irrigation systems have begun shrinking. During the 7-year period between 1994 and 2001, India and Pakistan together lost over 5.5 million ha of canal irrigated areas despite massive investments in rehabilitation and new projects (Shah

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[1] This article is based largely on the author's book *Taming the Anarchy: Groundwater Governance in South Asia*, Washington, D.C.: The Resources for the Future Press.

2008). In Central and Southeast Asia, figures are not as dismal; but the present performance and future sustainability of irrigation projects have remained a matter of growing concern.

Institutional Reforms in Surface Irrigation

In recent years, researchers, NGOs, donors and governments have sought to reverse this declining trend through institutional reforms-in the form of Participatory Irrigation Management (PIM) or Irrigation Management Transfer (IMT) to farmer associations. This idea itself derives from the variety of farmer-managed irrigation systems (FMIS) that proliferated-and can still be found-in Asia. As with all complex socio-technical systems, to work well, these systems required, generated, and nurtured a ‘culture of irrigation.’ So central was this culture to shaping the social lives of irrigators that anthropologist Robert Hunt called such groupings ‘irrigation communities.’ With large gravity-flow systems constructed by the state, system design and centralized operation acquired greater significance. But despite caution from the likes of Hunt and sociologist Walter Coward, it has been widely assumed that catalyzing and nurturing vibrant irrigation communities-water user associations-in command areas can help large irrigation systems function as well as traditional FMIS did. This assumption is now proving far-fetched.

For centuries, the feasibility of catalyzing a viable irrigation community determined the size of irrigation systems. Unsurprising, then, most FMIS were small-scale systems that could be sustained over centuries by local irrigation communities-often with cooperation aided by coercion from local authority structures. These survived and thrived as long as they met three ongoing challenges facing all multiuser irrigation systems:

Rule enforcement: Rules were enforced to keep in check the *anarchy* endemic to these systems by punishing deviations such as water thefts, vandalism and violation of distribution norms. Anarchy-control ensured efficient and equitable provision of irrigation service and helped maximize ‘member-value’ but required deft system-management backed by authority.

Regular maintenance: There was regular maintenance to counter the *atrophy* endemic to irrigation systems due to gradual disfigurement, arrested only by constant investment in their maintenance and upkeep. Atrophy-control ensured physical sustainability of the systems—which sometimes lasted for centuries—but required ruthless collection of irrigation service fees, often in the form of labor.

Upgradation: Systems were upgraded to minimize the *noise* by adapting the system to changing service-expectations of irrigators as changes in farming systems modified irrigation demands. The control of noise-the gap between the service system is capable of delivering and the service irrigators’ demand at a point in time-is minimized by constant upgradation to meet changing irrigation demand patterns. Until some decades ago, noise-control was not much of an issue in Asian irrigation. However, during recent decades, with household farming systems in the throes of massive change, noise-control has become a critical driver of irrigation system performance.

Clearly, authority-constituted endogenously within the irrigation community or provided from outside-was always central to sustained control of anarchy and atrophy. Large systems were therefore built and managed effectively only when external authority could enforce rules, and secure resources and labor for maintenance and repair. The colonial state had the necessary authority as well as the incentive to keep anarchy and atrophy in check. In many parts of Asia, the post-colonial state has neither. Moreover, noise was never as important a performance-depressant in Asian irrigation systems as it is today, what with farmers expecting on-demand irrigation year-round to support intensification and diversification of their subsistence farming. In this sense, decline in community and public irrigation systems is a reflection of larger changes underway in the Asian state and society.

Changing Socio-Technical Foundations of Asian Irrigation

Table 1 summarizes a broad-brush selection of socio-technical conditions that prevailed during precolonial, colonial and postcolonial eras in many Asian countries. The hypothesis is that particular forms of irrigation organizations we find in these eras were in sync with the socio-technical fundamentals of those times. Irrigation communities thrived during precolonial times when (a) there was no alternative to sustained collective action in developing irrigation, (b) strong local authority structures, such as *Zamindars* in Mughal India, promoted—even coerced—collective action to enhance land revenue through irrigation and (c) exit from farming was difficult.

Similarly, in the colonial times, large-scale irrigation systems kept anarchy, atrophy and noise in check because (a) land revenue was the chief source of government income, and enhancing it was the chief motive behind irrigation investments; (b) the state had a deep agrarian presence and used its authority to extract 'irrigation surplus' and impose discipline in irrigation commands; and (c) farmers had practical alternatives not as subsistence farming livelihoods or as gravity flow irrigation. These socio-technical conditions created an 'institutional lock-in' which ensured that public irrigation systems performed in terms of criteria relevant to their managers in those times.

Postcolonial Asian societies are confronted with a wholly new array of socio-technical conditions in which neither irrigation communities nor disciplined command areas are able to thrive. The welfare state's revenue interests in agriculture are minimal; the prime motive for irrigation investments is food security and poverty reduction, and not maximizing government income. Governments have neither the presence and authority nor the will to even collect minimal irrigation fees needed to maintain systems. So, agrarian economies are in the throes of massive change. Farmers can—and do—exit from agriculture with greater ease than ever before. Growing population pressure has made smallholder farming unviable except when they can intensify land use and diversify to high-value crops for growing urban and export markets. Finally, gravity flow irrigation systems are hit by the mass availability of small pumps, pipes and boring technologies that have made the 'irrigation community' redundant; these have also made the irrigators impervious to the anarchy, atrophy and noise in surface systems, and therefore reduced surface systems' stake in their performance.

Table 1. Socio-technical context of surface irrigation in different eras.

	Precolonial (adaptive irrigation)	Colonial (constructive imperialism)	Postcolonial (atomistic irrigation)
Unit of irrigation organization	Irrigation community	Centrally managed irrigation system	Individual farmer
Nature of the state	Strong local authority; state and people lived off the land; forced labor; maximizing land revenue chief motive for irrigation investments.	Strong local authority; land taxes key source of state income; forced labor; maximizing land revenue and export to home-markets chief motive for irrigation investments; state used irrigation for exportable crops.	Weak state and weaker local authority; land taxes insignificant; poverty reduction, food security and donor funding key motives for irrigation investments; forced labor impossible; electoral politics interfere with orderly management.
Nature of agrarian society	No private property in land. Subsistence farming, high taxes and poor access to capital and market key constraints to growth; escape from farming difficult; most command area farmers grow rice.	No property rights in land. Subsistence farming and high taxes; access to capital and market key constraints to growth; escape from farming difficult; tenurial insecurity; most command area farmers grow uniform crops, mostly rice.	Ownership or secure land use rights for farmers; subsistence plus high-value crops for markets; growing opportunities for off-farm livelihoods; intensive diversification of land use; command areas witness a wide variety of crops grown, with different irrigation scheduling requirements.

Demographics	Abundant land going begging for cultivation; irrigable land used by feudal lords to attract tenants.	Abundant land going begging for cultivation; irrigable land used by feudal lords to attract tenants.	Population explosion after 1950 and slow pace of industrialization promoted ghettoization of agriculture in South and Southeast Asia and China.
State of irrigation technology	Lifting of water as well as its transport highly labor-intensive and costly.	Lifting of water as well as its transport highly labor-intensive and costly.	Small mechanical pumps, cheap boring rigs, and low-cost rubber/PVC pipes drastically reduce cost and difficulty of lifting and transporting water from surface water and groundwater.

Rise of Atomistic Irrigation

Shrinking of surface irrigation does not mean irrigation areas of Asia are declining overall. In fact, they are not. Old community and government-managed systems are rapidly giving way to a new atomistic mode of irrigation in which millions of smallholders are creating their own mini irrigation systems and scavenge water at will using mechanical pumps, wells and rubber/PVC pipes. The rise of this new water-scavenging irrigation economy is most visible in South Asia and North China plains; here pump irrigation has begun dominating not only dryland areas but also irrigated areas where public and community irrigation ruled the roost until around the 1960s. In India, for example, even as governments keep investing in large, centrally managed surface irrigation projects, over 60% of irrigated areas are today under atomistic pump irrigation. Farmers in India, Pakistan, Bangladesh and Nepal have created more irrigation under this atomistic mode in the past 30 years than governments and colonial powers had created 200 years earlier. During the 1950s and 60s, Mao's China built massive irrigation systems to water North China plains; but today, the region irrigates mostly with small pumps and boreholes.

The same trend is now also evident in rice economies of Southeast Asia home to gravity flow irrigation communities for a long time. In Sri Lanka, known for its centuries-old tank irrigation of rice paddies, farmers were unfamiliar with irrigation pumps until the 1980s but were using some 106,000 by 2000 to scavenge water from whatever source-wells, tanks, streams-to irrigate dry-season rice and vegetables. By 1999, Vietnamese farmers had pressed into service more than 800,000 diesel pumps; and in Thailand, farmers increased their pumps from 500,000 in 1985 to more than 3 million in 1999. And the trend was just picking up; Francois Molle found that between 1995 and 1999 alone, Vietnamese farmers had purchased 300,000 irrigation pumps, and Thai farmers had added a million. Between 1998 and 2002, Indonesian farmers increased their pumps from 1.17 million to 2.17 million. In the Philippines, David Dawe noted that "approximately 23 percent of rice farms now use pumps to access water, either from sub-soil reservoirs, drainage canals, or natural creeks and rivers."

Observers have been struck by the pace of spread of pump irrigation in Southeast Asia. In the Chao Phraya Delta of Thailand, 80% of farmers were said to have at least one pump, and in Thailand's Mae Klong project, the World Bank has estimated that in the early 1990s, a million pumps were drawing water from canals, drains, ditches and ponds to irrigate dry-season crops. Regarding the Makhamtao-Uthong canal system in Chao Phraya, Facon wrote: "Use of groundwater for irrigation has exploded during the last five years. It is reported that 28,000 tubewells (sic) are in use in the region … All the farmers interviewed during the field visit reported having individual pumping equipment used to pump from any possible source of water." The irrigation scene in Asia resembles a palimpsest, with layers of old systems of irrigation getting removed to make room for the next one of atomistic, water-scavenging irrigation.

The boom in water-scavenging irrigation is supported by the rapid rise of the Chinese pump industry, which has pared the cost as well as the weight of their diesel pumps to a fraction of their competitors' products. The Chinese export some 4 million diesel pumps annually, at a pump per hectare, and these are adding around 4 million ha of atomistic irrigation every year, mostly in South and Southeast Asia. What atomistic irrigation is able to do, that the community and public surface irrigation are unable to match, is help farmers control the noise endemic to surface irrigation systems. Hard-pressed by shrinking landholdings and energized by growing markets for high-value farm products, Asia's smallholders are intensifying as well as diversifying their farming systems; this requires on-demand irrigation year-round. Atomistic irrigation is responding to that call. It is making the farmer immune to the anarchy, atrophy and noise in surface systems, and reducing surface systems' stake in countering them.

The ascent of atomistic irrigation is at different stages in different parts of Asia just as the socio-technical fundamentals. In South Asia and North China plains, it is peaking, threatening the relevance of irrigation communities and public irrigation itself. In Southeast Asia, it is at the early stages but it is already making the control of anarchy and atrophy in surface irrigation a challenge. In Central Asia, the jury is out; well irrigation is rising, especially for backyard garden irrigation, but from a small base.

Reform or Morph?

In the midst of these changing socio-technical fundamentals, Asia's surface irrigation enterprise is up against some hard questions. Everywhere, PIM/IMT is being tried as the panacea. But can PIM/IMT help restore control of anarchy and atrophy in irrigation systems? Can institutional reforms ensure financial and physical sustainability? Can these help improve rehabilitation of Asia's surface irrigation systems? The evidence from some decades of experiments is far from encouraging; by far the most celebrated experiments-catalyzed, sustained and micro-managed by NGOs with the help of unreplicable quality and scale of resources and donor support-report only modest gains in terms of performance and sustainability, leading researchers to demand 'reform of reforms.'

Low, uncollected irrigation service fees, growing deferred maintenance, rampant anarchy and inequity in water distribution in Asian surface irrigation systems are symptoms of a larger malaise that PIM/IMT seems unable to address. Unlocking value from Asia's public irrigation capital demands a nuanced exploration of the farmer-system interplay in the context of today's socio-technical fundamentals which differ across Asia. Table 2 presents a first-cut view of the socio-technical environment in which irrigation systems function in Central Asia, South Asia, Southeast Asia and China. Institutional reforms of the PIM/IMT kind appear to have best prospects in Central Asia especially if integrated in the estate-mode of irrigated agriculture that European colonial powers popularized in Africa. In China, the model of contracting out distributaries to incentivized contractors seems to have produced better results compared to PIM; and this model needs to be improvised and built upon. The authority and backing of the Village Party Leader seems essential for such privatization to work; and for that reason, this model is unlikely to work in South Asia and Southeast Asia. In Southeast Asia, the key may lie in upgrading and modernizing rice irrigation systems to support dry-season rice cultivation as well as diversification of farming systems.

The situation in South Asia suggests that instead of institutional reforms, surface irrigation systems here themselves need to morph to fit in to today's socio-technical context. For millennia, irrigation systems were 'supply-driven.' They offered a certain volume of water at certain times with a certain dependability and farmers had no option but to adapt their farming systems to these; they adapted because doing so was better than rain-fed farming. Atomistic irrigation—offering water-on-demand year-round—has turned South Asian irrigation increasingly 'demand-driven,' giving a whole new meaning to the term 'irrigation management.' With the option of 'exit' available, farmers in command areas are now reluctant to exercise 'voice' through PIM/IMT, refusing to give their loyalty to an irrigation regime that cannot provide them irrigation on-demand year-round.

Table 2. Socio-technical environment of Asia's surface irrigation systems.

	Central Asia	South Asia	Southeast Asia	China
1. State's revenue interest in irrigation agriculture	High	Low	Low	Low
2. State's capacity to enforce discipline in irrigation systems	Some to high	Low	Low	High

3. Crops in irrigation commands	Cotton and/or wheat	Monsoonal and summer rice, wheat, cotton, sugarcane, fodder, vegetables and fruit	Wet and dry season rice; high-value market crops	Rice
4. Government compulsory "levy" of irrigated crops	Yes	No	No	Not any more
5. Spread of pump irrigation within irrigation commands	Low	Very high	High	High
6. Population pressure on farmland	Low	Very high	High	High
7. Ease of exit from farming	Low	Some	High	High
8. Core strategy for unlocking vlue	Improvise on estate-mode of irrigation farming with PIM or entrepreneurial model in distribution.	Adapt surface irrigation systems to support and sustain atomistic irrigation.	Modernize irrigation systems to support dry-season rice and diversified farming.	Improvise and build upon the incentivized contractor model for distribution and fee collection.

If we are to unlock the value hidden in South Asia's surface irrigation systems, they must morph in ways they can support and sustain the rising groundswell of atomistic irrigation; and by doing that secure the resources and cooperation they need from farmers to counter anarchy, atrophy and noise. If they themselves cannot become demand-driven, they should try integrating with a demand-driven atomistic irrigation economy. This is already happening in many systems but by default; but much hidden value can be unlocked if this happens by deliberate design. This requires a paradigm shift in irrigation thinking and planning.

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Cost and Benefits of the National River Linking Project: An Analysis of Peninsular Links

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Abstract

Water, a critical component of food, livelihood and economic security, has always received a central place in India's investment portfolios. The investment in water transfers of the National River Linking Project (NRLP) is one of the biggest proposed in recent times. When and if completed, the NRLP forms a gigantic water grid covering most of South Asia. It envisages transferring 174 billion cubic meters (Bm^3) of water across 34 river links and will cost about US$120 billion (2000 prices). The proposed plan has aroused a large interest in recent public discourses. Hydrological feasibility, financial viability and social cost are the issues that dominate these public dalogues. This paper analyzes the cost and benefits of eight river links in the peninsular component, which include the main subcomponent of linking rivers of Mahanadi, Godavari, Pennar and Cauvery. Irrigation is the main beneficiary in this component and, en route, these links or canals account for 85% of the total water transfers to irrigation and domestic and industrial sectors in the command areas. However, our analyses show mixed results of financial viability of individual links. The main reason for this is low net value-added benefits from additional irrigation over and above the existing level of cropping and irrigation patterns. The proposed cropping patterns of these links generate much less net value-added benefits than the existing cropping and irrigation patterns. To make these links financially viable, they need to include high-value cropping patterns that, at least, generate as much benefit per unit area as fruits and vegetables.

Although some individual links show less than desirable net benefits, taken together the Mahanadi-Godavari-Pennar-Cauvery subcomponent gives a higher internal rate of return of 14% compared to a discount rate of 12%, and a high benefit-cost ratio of 1.3. However, many unknown factors or unavailable information in this analysis can alter the estimates of financial benefits and costs.

Introduction

The importance of access to water in India's national food security is well recognized. Access to irrigation was a critical determinant for the success of the green revolution, which transformed India's chronic food deficits in the 1960s to a state of food self-sufficiency in the 1970s. The effect of irrigation on productivity growth, as a direct input and as catalyst for other high-value agronomic inputs, continued and spread to vast rural landscapes. High productivity growth was indeed a major reason for livelihood security that decreased poverty in rural areas. Today, access to water is a vital component of national economic growth. However, with increasing population and urbanization with expanding industrial and service-sector economic activities, many regions in India are facing extreme physical to economic water scarcities (Amarasinghe et al. 2005). Water is physically scarce in southern and western India, where available resources are not adequate for further development without deleterious consequences to the environment. But, water is plenty in the east and northeast India, where floods damage agriculture and infrastructure, causing human misery year after year. The negative impact, due both to droughts and floods, will likely increase with climatic change (Gosain et al. 2008). Indeed, India is facing a water crisis. It is a crisis comprising scarcity, on the one hand, and plenty, on the other. The crisis needs to be urgently managed, and India is facing the dilemma of how to face this water crisis.

India's proposed NRLP is claimed to be a part of a solution to the pending water crisis (NWDA 2008). It envisaged diverting surplus floodwater from the northeastern and eastern rivers to water-scarce south and west. The Brahmaputra, Mahanadi and Godavari are primarily the donors in the NRLP, while Krishna, Pennar and Cauvery in the south and Sabramati and Mahi in the west are the main recipients. Once completed, the project will impound water in reservoirs both in and outside India, transfer and distribute water through an extensive network of canals to irrigate more than 34 million ha, generate 34 GW of hydropower, meet domestic and industrial demands in many cities, recharge groundwater to relieve overexploitation, reduce flood damage, and create direct and indirect employment to many people in the water-recipient regions.

The NRLP has two major components: the Himalayan and the peninsular. The Himalayan component, with 16 river links, primarily facilitates the transfers of the surplus water in the east to the Ganga Basin and water-scarce basins in the west of Peninsular India. The peninsular component with 14 river links, mainly transport and distribute the surplus water to the water-scarce regions within the peninsular river basins. Both components will have about 3,000 storages to connect 37 rivers, and they will form a gigantic water grid, which South Asia has never witnessed in the history of water development. Yet, the NRLP plan drew wide criticism from a wide range of stakeholders, including the civil society, academia, environmental community, policy planners and politicians. The criticisms are partly due to its gigantism, in which the project costs colossal amounts of money when India badly needs investments for developing social and physical infrastructure and which brings enormous environmental damages by transporting water long distances displacing a large number of people and submerging large swaths of productive agricultural land, homesteads, forests, etc. Many people also argue that the economic benefits that NRLP generates will not be sufficiently high vis-à-vis the social and environmental costs that it creates. But, many of the arguments for and against the NRLP lack sufficient analytical rigor.

The research project, "The Strategic Analyses of National River Linking of India," of the Challenge Program on Water and Food (CPWF) and the International Water Management Institute (IWMI) is trying to fill the void created by the lack of analytical rigor and informs the public better of the discourse on NRLP (CPWF 2005). The project also raises many strategic issues regarding the state of the water sector that India needs addressing for preventing a pending water crisis with or without the NRLP.

A water development project generally originates from a water futures assessment. The major source for NRLP was the scenario's assessment of the National Commission of Integrated Water Resources Assessment (NCIWRD 1999). But, the drivers, both exogenous and endogenous, of water demand and supply are changing rapidly. The publication "India's Water Futures: Scenarios and Issues" (Amarasinghe et al. 2009), discusses scenarios and issues that emanate from this fast-changing status of drivers. India has a large rural population with agriculture-dependent livelihoods. Meeting livelihood security of the rural masses and food security at the national level is the foremost priority of policy planners. As a result, many large water development projects have been proposed and implemented to date. However, the proposed NRLP is such a gigantic water grid that India and, for that matter, the whole of South Asia have never dreamt of implementing before. Thus, issues embedded in the NRLP are many, requiring more attention than previous water development projects. In the proceedings of the national workshop "Social, Hydrological and Environmental Issues of the National River Linking Project" (Amarasinghe and Sharma 2008) many issues related to the NRLP project are discussed.

This paper assesses the financial benefits and costs of some of the proposed peninsular links. The primary focus of the assessment is on irrigation benefits. Of all water transfers of the NRLP, irrigation is the major beneficiary. The benefit analysis in this paper focuses on the changes of India's irrigation landscape since the project proposal came into existence. Thus, we develop scenarios of benefit streams on the level of irrigation that could already be in the proposed command areas. After a brief introduction of the domain of analysis in the next section, we explain the methodology in detail in the section on methodology of benefit assessment. Then follows the section on the benefit and cost scenarios of the links in the study. Lasr, we conclude the paper with a discussion of issues arising out of this analysis for consideration for further analyses.

Links in the Study

This study assesses financial benefits of eight links in the peninsular component (Figure 1) that connect Mahanadi, Godavari, Pennar and Cauvery river basins. These include Link 1 connecting Mahanadi and Godavari, Links 2, 3 and 4 connecting Godavari and Krishna, Link 7 connecting Krishna and Pennar[1], Link 8 connecting Pennar-Palar-Cauvery and Link 9 connecting Cauvery to Vaigai and Gundai subbasins in Tamil Nadu. The full implementation of these links is largely dependent on water transfers between one another. Water transfer from Mahanadi to Godavari facilitates water transfer from Godavari to Krishna that, in turn, facilitates water transfer to Pennar, and then to Cauvery. Additionally, we include the link connecting Pamba to Achankvoil-Vaipar, transferring surplus water from Kerala to Tamil Nadu.

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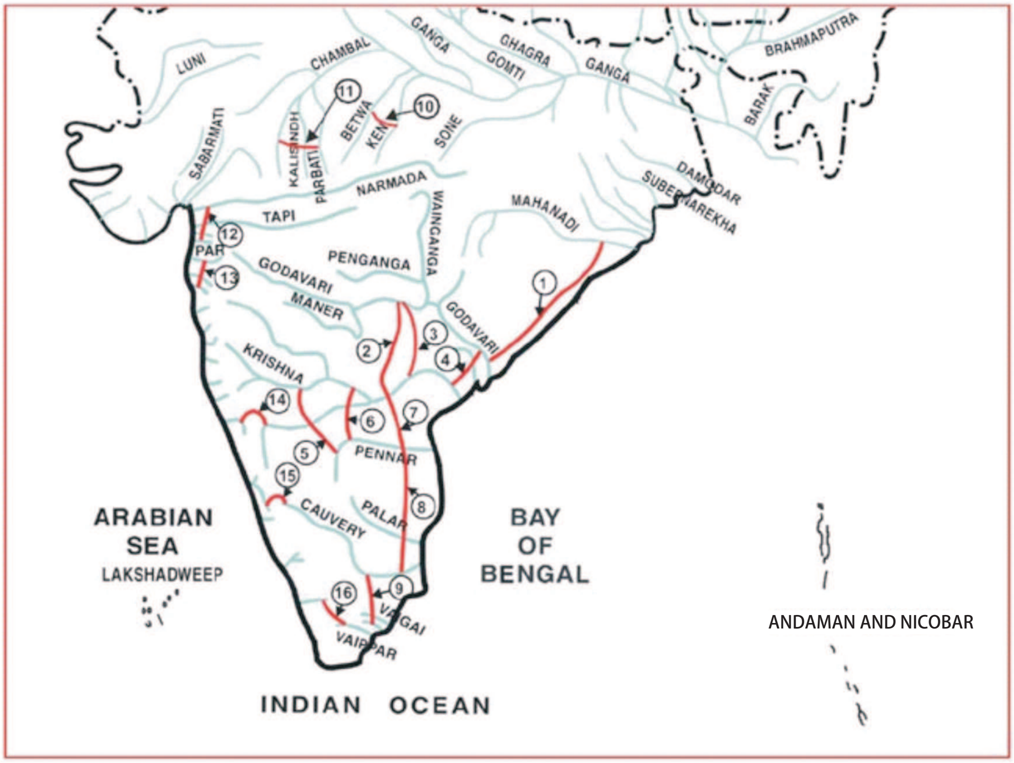
[1] Links 5 and 6 were not considered for this analysis. Water transfers through these links from Krishna to Pennar are only substitutes for the water transfers from Krishna to Pennar from the Nagarjunasagr-Pennar links.

Figure 1. River links in the peninsular component.

PROPOSED INTERBASIN WATER TRANSFER LINKS,
PENINSULAR COMPONENT



1. Mahanadi (Manibhadra) - Gadavari (Dowlaiswaram)*
2. Godavari (Inchampalli) - Krishna (Nagarjunasarar)*
3. Godavari (Inchampalli) - Krishna (Pulichintala)*
4. Godavari (Polavaram) - Krishna (Vijayawada)*
5. Krishna (Almatti) - Pennar*
6. Krishna (Srisailam) - Pennar*
7. Krishna (Nagarjunasagar) - Pennar (Somasila)*
8. Pennar (Somasila - Palar - Couvery (Grand Anicut)*
9. Cauvery (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*

* Feasibility reports completed

Links in the analysis include:

- The uppermost link of the peninsular component links Mahanadi (Manibhadra) and Godavari (Dowlaiswaram) rivers. The primary objective of this link is to transfer surplus water of the Mahanadi Basin. While doing so, en route, this link provides water for irrigation, domestic purposes and industries and meets the water demands of the downstream from Dowlaiswaram in the Godavari Basin. The latter is only a substitute for the water transfers from Godavari to the Krishna Basin via three links upstream of Dowlaiswaram.
- Godavari (Inchampalli)-Krishna (Nagarjunasagar) is the uppermost link originating from the Godavari Basin and, en route, this link also supplies water for irrigation, domestic and industrial purposes, and then transfers water from Krishna to the Pennar Basin at Nagarjunasagar.

- Godavari (Inchampalli)-Krishna (Pulichintala) is the middle link originating from the Godavari Basin and, en route, this water provides only for irrigation and domestic and industrial purposes.
- Godavari (Polavaram)-Krishna (Vijayawada) is the lowermost link from the Godavari Basin. The primary objective of this link is to facilitate water transfer from Krishna to Pennar by way of substituting the water demand of Krishna below Vijayawada. This link also has major provisions for irrigation, and domestic and industrial purposes en route from the canal command.
- Krishna (Nagarjunasagar)-Pennar (Somasila) Link, one among the three links originating from Krishna to Pennar, provides water en route for irrigation and domestic and industrial purposes, and facilitates water transfer from the Pennar to the Cauvery Basin.
- Pennar (Somasila)-Palar-Cauvery Link, facilitating transfer of water received from Krishna to the Cauvery Basin,
- Cauvery (Kattalai)-Vaigai-Gundai Link, which transfers water from smaller basins of Cauvery. This link also provides water for irrigation and the domestic and industrial sectors.
- The last link in the study transfers water from Pamba to Achankvoil-Vaipar subbasins for irrigation, which is an independent component in the peninsular basins.

The eight links considered in this analysis transfer 61 Bm^3 of water, accounting for 35% of the total water transfers in NRLP and, en route, these canals provide 18.3 Bm^3 irrigation to 2.9 million ha (Mha) of culturable land and meet 3 Bm^3 of domestic and industrial needs.

En route, the command areas cut across 33 districts and include 0.256 Mha of croplands in six districts in Orissa, 1.4 Mha of nine districts in Andhra Pradesh, and 0.823 Mha of 17 districts in Tamil Nadu (Table 1).

According to feasibility reports prepared by the National Water Development Agency (NWDA 2008a-f), the total cost of supplying water to en-route commands of eight links is US$6,257 million (Table 2), which is 41% of the total cost. This is only the apportioned cost of water supply to en-route commands. For example, Mahanadi-Godavari diverts water not only for the en-route command but also for Godavari Delta. The latter is a substitution for the diversions from the upstream location in Godavari to the Krishna Basin. It also generates hydropower to be used outside the en-route canal. The total cost of the project is US$3.9 billion, of which the en-route command accounts for only 35%.

The total cost estimate of the eight links is US$15 billion, which is only 12% of the cost estimate of the whole NRLP project.

Table 1. Details of river links in the study.

	Name of link	Water transfers from the canals									
		Total	Down-stream diversion	En-route water distribution			En-route irrigated area distribution				
				Irrigation	Domestic and industrial	Losses	CCA[1]	Area of water receipts	Share of CCA	Districts in CCA	Share of CCA in districts
		Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	ha		ha		ha
1	Mahanadi (Manibhadra)-Godavari (Dowlaiswaram)	12,165	6,500	3,790	802	1,073	363,959	Orissa	256,770	Nayagarh	28,057
										Khurda	106,317
										Cuttack	20,448
										Puri	9,714
										Ganjam	92,091
										Gajapati	143
								Andhra Pradesh	88,578	Srikakulam	73,499
										Vizianagara	15,079
										Vishakapatnam	18,611
2	Godavari (Inchampalli)-Krishna (Nagarjunasagar)	16,426	14,200	1,427	237	562	255,264	Andhra Pradesh	255,264	Warangal	70,021
										Nalgonda	147,651
										Khammam	37,592
3	Godavari (Inchampalli)-Krishna (Pulichintala)	4,370		3,665		290	467,589	IRBC- AP	48,230	Warangal	24,115
										Khammam	24,115
								NSLBC-AP	6,900	Krishna	4,600
										Khammam	2,300
								NSLBC-LIFT-AP	203,369	Krishna	101,685
										Khammam	101,684
								NSLBC b.Tammi	137,975	West Godavari	137,975
								NSRBC -AP	71,115	Guntur	4,600
										Prakasam	66,515
4	Godavari (Polavaram)-Krishna (Vijayawada)	5,325	3,501	1,402	162	260	139,740	Andhra Pradesh	139,740	West Godavari	69,870
										Krishna	69,870

Table 1 (continued)

	Name of link	Water transfers from the canals									
		Total	Down-stream diversion	En-route water distribution			En-route irrigated area distribution				
				Irrigation	Domestic and industries	Trans-mission losses	CCA	Area of water receipts	Share of CCA	Districts in the CCA	Share of CCA in districts
		Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	(ha)		(ha)		(ha)
7	Krishna (Nagarjunasagar)-Pennar (Somasila)	12,146	8,426	3,264	124	332	581,017	Andhra Pradesh	168,017	Prakasam	84,008
										Nellore	84,008
								Andhra Pradesh	413,000	Nagarjunsagar RBC	413,00
8	Pennar (Somasila)-Palar-Cauvery (Grand Anicut)	8,565	3,855	3,048	1,105	557	599,000	Andhra Pradesh	283,553	Nellore	132,569
										Chittoor	150,984
								Tamil Nadu	315,447	Tiruvallur	34,492
										Vellore	61,218
										Kancheepur	44,657
										Tiruvannama	62,366
										Villupuram	72,702
										Cuddalore	37,052
										Pondicherry	2,962
9	Cauvery (Kattalai)- Vaigai-Gundar	2,252	-	1,067	185	115	452,000	Tamil Nadu	452,000	Karur	45,020
										Tiruchchirap	68,462
										Pudukkottai	72,489
										Sivaganga	65,120
										Ramanathapu	63,581
										Virudhunaga	65,959
										Thoothukudi	71,369
16	Pamba-Achankvoil-Vaipar	635	-	635	-	-	56,233	Tamil Nadu	56,233	Tirunelveli	30,765
										Tuticorin	386
										Virudhunaga	25,082

Note: CCA stands for cultivable command area

Sources: NWDA 2008a-h.

Table 2. Total cost of supplying water to en-route commands of the eight links.

	Name and no. of link in the peninsular component (see Figure 1)	Total cost[1] (Rs million)	Year of cost level assessment	Financial exchange rate of US$1 in Rs	Capital cost in million US$ (in 2003-04 constant prices)
1	Mahanadi (Manibhadra)-Godavari (Dowlaiswaram)	63,018	2003-04	46.0	1,370
2	Godavari (Inchampalli)-Krishna (Nagarjunasagar)	27,540	2003-04	46.0	599
3	Godavari (Inchampalli)-Krishna (Pulichintala)	50,460	2003-04	46.0	1,097
4	Godavari (Polavaram)-Krishna (Vijayawada)	14,839	1994-95	31.4	473
7	Krishna (Nagarjunasagar)-Pennar (Somasila)	8,806	1998-99	42.1	209
8	Pennar (Somasila)-Palar-Cauvery (Grand Anicut)	4,170	2003-04	46.0	1,472
9	Cauvery (Kattalai)-Vaigai-Gundar Link	26,730	2003-04	46.0	581
16	Pamba-Achankvoil-Vaipar	139,79	1992-93	30.6	457
	Total	242,597		334.1	6,257

[1] This cost estimate is based on the feasibility reports prepared by the NWDA (NWDA 2008a-h). These costs are assessed in constant prices of various years. The last column shows the cost estimates in constant 2003 prices.

Methodology of Benefit Assessment

We estimate financial benefit-cost ratio (BCR) and internal rate of return (IRR) of water supply to en-route commands of the eight links. The financial benefit-cost analysis indicates long-term financial viability of the proposed links. This is different from an analysis of social benefits and costs that assesses how a project affects the society in total. The incremental net benefits and costs to the participants, whom the project directly affects, is the basis for the financial analysis. The analysis of social and economic benefits and costs assesses the effect of the project on the national or regional economy and society. Indeed, for a project to be economically and socially viable, first it must be financially sustainable, and second the social and economic benefits should exceed the cost over the life span of the project.

The primary reason for focusing on a financial benefit-cost analysis in the study is data availability. We have a sufficiently accurate long-term secondary database for the assessment of net financial benefits of the en-route command. However, only limited information is available for estimating the social and environmental costs. In our analysis, first we estimate the net present value (NPV) of each link, which is the present value of net incremental value-added benefit that the project will accrue over its lifetime. Discounting the net incremental benefits of a base year over the project life span with an appropriate discount rate gives the NPV:

$$NPV = \sum_{t=0}^{N+N_0} \frac{(B_t - C_t)}{(1+r)^t}$$

where, B_t is the net value-added benefits in period t; C_t is the project cost in period t; r is the appropriate financial discount rate; N_0 is the number of years before the project providing intended benefits, and N is the effective life of the project. A positive NPV indicates that the investment is worthwhile for generating positive financial returns. We also estimate the Internal Rate of Return (IRR) to assess the discount rate at which the project is a financially viable venture. The IRR is the discount rate at which the NPV equals zero.

A major part of the water transfers of the links is for irrigation. Of the eight links, 76% of the water transfers to en-route command areas is for irrigation, and 10% for meeting domestic and industrial water needs (Table 1). Further, 14% is accounted for as transmission losses. Thus, a primary focus of this analysis is to estimate the net value-added benefits of crop production (B_t^{crops}). We estimate the net benefit of crop production of a link by aggregating the benefits over districts that intersect the link command area. Benefits of new irrigation on a district include net value-added crop output (NVACOUP) and the indirect benefits are generated through forward and backward linkages with increased irrigation. This paper mainly deals with estimation of direct benefits. However, we draw from the results of other benefit-cost studies of water transfers to estimate the indirect effects. Bhatia and Malik (2007) estimated a multiplier value of 1.9 for the Bhakra irrigation project in Haryana. This means that for every $100 of direct benefits that new transfers generate, another $90 is generated, for the region where the project is located as a multiplier effect. For smaller projects, the multiplier effect has a smaller value, ranging from 1.1 to 1.4. Since the proposed command areas of the links are relatively smaller than the Bhakra irrigation project, we assumed 1.4 as the multiplier effect for estimating indirect benefits. So,

$$B^{crops} = 1.4 \times NVACOUP$$

The feasibility reports (NWDA 2008 a-h) indicate that parts of the proposed command areas of many links do already receive irrigation from small surface water schemes. Given the recent trends of land use patterns, it is likely that groundwater irrigation has also spread to many parts of the proposed command area (Annex Table 1 for changes in land use patterns of 33 districts). For example, Bhaduri et al. (2008) estimated that more than 90% of some districts in the en-route command area of the Godavari (Polavaram)-Krishna (Vijayawada) Link at present use groundwater irrigation. In the Ken-Betwa, another smaller link in the peninsular component, groundwater irrigation could have expanded to 35% of the command area (Amarasinghe et al. 2008). Of the 33 districts in the eight links, groundwater-irrigated area has increased significantly between 1985 and 2005. Groundwater irrigation varies from 7 to 73% of the net irrigated area in Andhra Pradesh, and 20 to 86% in Tamil Nadu.

Thus, water transfers of new links contribute to increase NVACOUP in the command areas in two ways. They change, (a) cropping intensity and cropping patterns and increase crop output on the already irrigated portion inside the proposed command areas and, (b) the yield, cropping intensity and cropping patterns in the rain-fed areas of the proposed command.

The total net value-added output ($\text{NVACOUP}^{\text{crops}}$) in each link is:

$$NVACOUP^{crops} = \sum_{i \in districts} \left(\begin{array}{l} A_{io}\left(\sum\limits_{j \in crops} (CP_j - CP^{IR}_{ijo}) \times (Y^{IR}_{ij} \times p_j - C^{IR}_{ij0}) \right) + \\ (A_i - A_{i0}) \times \left(\sum\limits_{j \in crops} \left(\begin{array}{l} CP_j \times (Y^{IR}_{ij} \times p_j - C^{IR}_{ijo}) - \\ \qquad CP^{RF}_{ijo} \times (Y^{RF}_{ij} \times p_j - C^{RF}_{ijo}) \end{array} \right) \right) \end{array} \right)$$

where, *i* varies over districts in the command area and *j* varies over 11 crops or crop categories, including rice, wheat, maize, other cereals, pulses, oilseed, sugar, fruits, vegetables, cotton and other crops including fodder, etc. Also,

A_i - culturable command area of the link in the ith district,
A_{i0} - culturable command area of the link in the ith district irrigated in 2000,
CP_j - share of the area of crop *j* in the proposed cropping patterns,
CP^{IR}_{ijo} - share of the irrigated area of crop *j* in district *i* in 2000,
CP^{RF}_{ijo} - share of the rain-fed area of crop *j* in district *i* in 2000,
Y^{IR}_{ijo} - irrigated yield of crop *j* in district *i* in 2000,
Y^{RF}_{ijo} - rain-fed yield of crop *j* in district *i* in 2000,
C^{IR}_{ijo} - cost of cultivation of crop *j* in district *i* in 2000 under irrigation conditions,
C^{RF}_{ijo} - cost of cultivation of crop *j* in district *i* in 2000 under rain-fed conditions, and
p_j - average export price of crop *j* in 1999-2001.

The secondary data for this analysis were available from various sources. This includes the Directorate of Economics and Statistics (GOI 2008) for the trends of cropping and irrigation patterns at the district level and cost of production data at the state level: IWMI PODIUMSIM model (Amarasinghe and Sharma 2008) for irrigated and rain-fed crop yields at the district level; and the FAOSTAT database (FAO 2008) for the world export prices.

In addition to the increases in crop production, water transfers also generate other benefits in the form of hydropower generation, and water transfers to domestic and industrial sectors. For these benefits, we rely on the estimates in the feasibility reports (NWDA 2008a-h). They also give the capital costs of construction of the links.

Scenarios of NVACOUP

This study estimates net value-added benefits of crop production in en-route command areas under different scenarios of increases in cropping intensity. The main reason for this is the available information on current cropping or irrigation intensity in the proposed command areas. Feasibility reports do not show what part of the proposed command area is new, or already irrigated, or under rain-fed conditions. Therefore, we consider four scenarios of assessing NVACOUP.

Scenario I assumes that the proposed command area is a completely new addition to the crop production base. Essentially, this means no crop production exists at present on the proposed command area, and hence A_{io}=0, and CP^{RF}_{ijo} =0. Obviously, this scenario would give the highest crop production benefits with new water transfers.

Scenario II assumes that the proposed command area is completely under rain-fed cultivation at present, indicating only A_{io}=0. Additionally, we assume that the share of crop area in the command area at present is the same as the share of crop area in the respective districts under rain-fed condition.

Scenario III assumes that maximum cropping intensity in the command areas at present is the minimum of the existing and the proposed command areas. This scenario assumes that maximum annual cropped area at present within the proposed command area is the cropped area proposed under full irrigation.

- For example, the current cropping intensity in districts covering the Mahanadi-Godavari en-route command area is 152% (Table 3). But we assume the current cropping intensity as only 131%, which is the same as the proposed cropping intensity under full irrigation. Only, 57% of that area is irrigated at present.
- In the districts covering Godavari (Inchampalli)-Krishna (Pulichintala) Link command, the current cropping intensity is 140%. But the proposed irrigation intensity is only 110%. So, in Scenario III we assume only 110% existing cropping intensity for Godavari (Inchampalli)-Krishna (Pulichintala) Link command.

Scenario IV assumes that irrigation is already available for a part of the command area. Also, the share of crop area in the command area under irrigated and rain-fed conditions at present is the same as that of the districts intersecting the command (Table 3). For example, the current cropping and irrigation intensities in the command area of Mahanadi-Godavari Link are assumed to be the same as those of the districts covering the command areas. In this case, the current cropping and irrigation intensities are 157 and 47%, respectively. However, the proposed irrigation intensity in the command area is 137%. This allows a part of the command area to be rain-fed even after water transfers; and the irrigation intensity in the Mahanadi-Godavari Link is 20% of the culturable command.

In all these scenarios, we assume the following in NVACOUP estimation:

- Feasibility reports show that a significant part of the command area is allocated for crops other than the 10 crops or crop categories mentioned above. We use the maximum of net value-added in the 10 crops to estimate the net benefits of other crops. In most links, this is the net value-added benefits of fruits and vegetables (Annex Table 2).
- The secondary data of cost of crop production under irrigation and rain-fed conditions at the district level are not available for this analysis. Depending on the availability of data and estimation constraints, we use a regression analysis of the state-level data from 2001 to 2004 to estimate the cost of production. The dependent variable of the regression analysis is the cost of production per ha and the independent variable is the percentage of irrigated area of crops. Additionally, a dummy variable captures other differences between states. In sugarcane, the total area is almost completely irrigated in most states. Therefore, we use the cost of production of irrigated sugarcane in Andhra Pradesh for the current analysis (these items of information are given in Annex Table 2).

Benefits and Costs

As expected, Scenario I, with no crop production before water transfers, has the highest NVACOUP, generating $1,898/ha of gross crop area (GCA) of all links (Table 4). Scenario II, with only one-season of rain-fed crop before water transfers, has the next highest NVACOUP, i.e., $1,040/ha.

- In Scenario II, all canals, except those in the Godavari (Inchampalli)-Krishna (Nagarjunasagar) Link, have positive net benefits. The negative benefits in these canals are mainly due to small differences in yields under irrigated and rain-fed areas at present and changes in proposed cropping patterns. The proposed cropping patterns in the Godavari (Inchampalli)-Krishna (Nagarjunasagar) Link do not have rice or other crops, which dominate the cropping patterns at present. Thus, in spite of increase in area under fruits and vegetables, with the highest net benefit/ha of different crops at present, the decreases in rice and other crops in the proposed cropping patterns have decreased the total NVACOUP.
- If the proposed cropping pattern is the same as that existing at present, then the NVACOUP increases from a negative 262/ha to a positive 2,093/ha.

Scenario III has the next best NVACOUP, i.e., $613/ha. This scenario still generates negative benefits in the Godavari (Inchampalli)-Krishna (Nagarjunasagar) Link, due to changes in cropping patterns. If the proposed cropping pattern is similar to that existing at present, then NVACOUP in this link changes from a negative $719/ha to a positive $411 /ha.

Scenario IV has the lowest benefits, i.e., $279/ha. Three out of the eight links under this scenario have negative value-added benefits. This is again mainly due to differences in cropping patterns. If the proposed cropping pattern is similar to that existing at present, then NVACOUP of the Godavari (Inchampalli)-Krishna (Nagarjunasagar) Link will increase from a negative $860/ha to a positive $134/ha.

This shows that the selection of a proper high-value cropping pattern, even after irrigation transfers, should be a necessary condition for the links to generate positive net benefits. Any drastic changes from the present cropping patterns, especially from fruits/vegetables and other high-value crops would not yield any crop production benefits in the proposed command areas. At present, fruits, vegetables, rice and sugarcane provide the highest value-added net benefit per ha of all crops (Table 2). For crop production to generate positive net benefits, the proposed cropping patterns should include a higher percentage of high-value crops. This is more important in the command areas, where yields of irrigated crops are not significantly higher than those of rain-fed crops.

Table 3. Existing and proposed cropping and irrigation patterns.

				Cropping and irrigation patterns (%).										
	No. and name of link. (Figure 1)	Net command area		Rice	Maize	Wheat	Other cereals	Pulses	Oil seeds	Sugarcane	Fruits and vegetables	Cotton	Other	Total
1	Mahanadi (Manibhadra) Godavari (Dowlaiswaram)	363,959	%CA-2000[1]	74	2	0	4	35	15	3	8	4	8	152
			%IA-2000[1]	47	0	0	1	2	1	3	3	1	0	57
			%CA (= %IA) - proposed	73	1	0	1	17	21	0	7	1	11	131
2	Godavari (Inchampalli)-Krishna (Nagarjunasagar)	255,264	%CA-2000[1]	42	4	0	6	17	12	0	5	12	21	119
			%IA-2000[1]	41	1	0	0	0	3	0	2	2	0	50
			%CA (= %IA) - proposed	0	15	0	28	17	22	0	10	8	0	100
3	Godavari (Inchampalli)-Krishna (Pulichintala)	467,589	%CA-2000[1]	66	4	0	2	20	4	6	5	12	21	140
			%IA-2000[1]	64	1	0	1	0	2	5	2	2	0	77
			%CA (= %IA) - proposed	0	0	0	0	15	45	0	30	10	0	100
4	Godavari (Polavaram)-Krishna (Vijayawada)	139,740	%CA-2000[1]	91	2	0	0	21	2	9	5	10	14	155
			%IA-2000[1]	91	2	0	0	0	1	8	2	2	0	106
			%CA (= %IA) - proposed	48	6	12	12	15	18	6	21	6	6	150
7	Krishna (Nagarjunasagar)-Pennar (Somasila) Link	168,017	%CA-2000[1]	54	2	0	3	28	6	3	5	13	23	135
			%IA-2000[1]	54	0	0	2	1	3	2	2	1	0	66
			%CA (= %IA) - proposed	25	0	0	24	10	15	0	4	9	13	100
8	Pennar (Somasila)-Palar-Cauvery (Grand Anicut)	599,000	%CA-2000[1]	46	0	0	5	10	31	10	4	4	7	118
			%IA-2000[1]	45	0	0	1	1	11	10	2	1	0	72
			%CA (= %IA) - proposed	18	4	0	10	14	15	0	5	13	20	100
9	Cauvery (Kattalai)-Vaigai-Gundar	452,000	%CA-2000[1]	54	1	0	7	4	14	3	4	4	12	103
			%IA-2000[1]	36	0	0	0	1	4	2	2	1	0	46
			%CA (= %IA) - proposed	15	5	0	10	10	20	0	20	20	0	100
16	Pamba-Achankvoil-Vaipar	56,233	%CA-2000[1]	61	2	0	3	7	13	3	5	4	15	113
			%IA-2000[1]	43	1	0	1	2	5	2	3	3	0	59
			%CA (= %IA) - proposed	15	0	0	13	12	15	0	20	15	0	90

[1] - CA-2000 and IA-2000 mean cropped and irrigated areas in 2000.

Table 4. Net value of crop output before and after water transfers.

	Name and no. of link (Figure 1)	Net value of crop output per ha of gross cropped area ($/ha in 2000 prices)											
		Scenario I			Scenario II			Scenario III			Scenario IV		
		Before	After	Change	Before	After	Change	Before	After	Change	Before	After	Change
1	Mahanadi-Godavari	0	948	948	622	948	326	668	948	280	703	864	161
2	Godavari–Krishna (Nagarjunasagar)	0	972	972	1,233	972	-261	1,681	972	-709	1,677	870	-807
3	Godavari-Krishna (Pulichintala)	0	2,792	2,792	1,125	2,792	1,667	1,672	2,792	1,120	1,651	2,114	463
4	Godavari-Krishna (Vijayawada)	0	1,874	1,874	697	1,874	1,177	1,357	1,874	517	1,360	1,834	474
7	Krishna (Nagar.)-Pennar (Somasila)	0	1,748	1,748	1,069	1,748	678	1,662	1,748	85	1,764	1,399	-365
8	Pennar (Somasila)-Palar-Cauvery	0	2,398	2,398	518	2,398	1,880	1,094	2,398	1,304	1,097	2,085	988
9	Cauvery (Kattalai)-Vaigai-Gundar	0	1,895	1,895	1,026	1,895	869	1,416	1,895	479	1,421	1,851	429
16	Pamba-Achankvoil-Vaipar	0	1,943	1,943	944	1,943	999	1,567	1,943	375	1,600	1,624	24
	All links	0	1,898	1,898	869	1,898	1,028	1,297	1,898	601	1,320	1,654	335

Net Present Value (NPV) and Internal Rate of Return (IRR)

In estimating NPV and IRR, we assumed a 12% annual discount rate, a 10-year construction period, project life span of 50 years and 10% of the capital cost as operation and maintenance costs. Total net value-added benefits of water transfers include:

- Net value-added benefits of crop production due to irrigation water transfers.
- Benefits of domestic and industrial[2] water transfers.
- Hydropower generation.[3]
- Indirect benefits of water supply assessed through a multiplier value, which we have taken as 1.4.

The net value-added benefit of a link is 1.4 times the net value-added crop output and domestic, industrial and hydropower benefits. The data show the percentage share of water supply and contribution to net value-added benefits by the irrigation, domestic and industrial sectors (Table 5). Clearly, a major part of the water deliveries is for irrigation. Of the eight links in this study, 85% of the water deliveries is for the irrigation sector, and 8 and 7% for domestic and industrial sectors, respectively. The contribution to net value-added benefits varies with existing extent of cropped and irrigated area. Scenario I has the highest contribution of irrigation to net value-added benefits. This contribution decreases from 88 to 62% from Scenarios I and IV.

The NPV, IRR and BCR of different links are given in Table 5. The results indicate the following:

- Under Scenario 1, all links except the Pamba-Achankvoil-Vaipar Link, have a significantly high IRR (16-39%) and BCR (1.3-6.9), showing that investments in the en-route canal command are financially viable. However, financial viability decreases with the assumption on existing cropped and irrigated areas in the proposed commands.
- If the en-route command at present has only rain-fed cropping (Scenario 2), then all links, except the Godavari (Inchampalli)-Krishna (Nagarjunasagar) and Pamba-Achankvoil-Vaipar links are financially viable. The proposed cropping pattern is the major reason for financial nonviability. If this link also has a high-value cropping pattern it can also be a financially viable option. If the proposed cropping patters are similar to those existing now, the BCR and IRR of the Godavari (Inchampalli)-Krishna (Nagarjunasagar) Link under Scenario 2 increase between 2.0 and 20%.
- A major part of the proposed command areas in all links already has some cropped area, and within that some irrigation. Scenarios III and IV correspond to these conditions. Under these scenarios, the IRR of all links, except the Godavari (Inchampalli)-Krishna (Nagarjunasagar), Krishna (Nagarjunasagar)-Pennar (Somasila) and Pamba-Achankvoil-Vaipar links, are more than the discount rate and BCR is more than 1, indicating that they will be financially viable investments with the projected benefit streams.

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[2] Benefits of domestic and industrial supply of all links are assessed at 5.00 and 14.50 Rs/m^3, respectively, of water deliveries, the rate used for assessing Godavari (Inchampalli)-Krishna (Nagarjunsagar) Links.

[3] Hydropower benefit is assessed at 1.67 per unit of kWh, the prevailing average rate per unit in Andhra Pradesh (NCAER 2009).

- These links whose proposed cropping patterns are quite different from those existing now have low irrigation benefits, low NPV and lower IRR and BCR. If the proposed cropping patters are similar to those existing now, the IRR and BCR of the Godavari (Inchampalli)-Krishna (Nagarjunasagar) Link under Scenario III increases to 14 and 1.1%, respectively. But the net benefits under Scenario IV still do not exceed the cost (BCR=0.7). With high-value cropping patterns, the Krishna (Nagarjunasagar)-Pennar (Somasila) Link can also generate large net benefits, high IRR and BCR.

Thus, it is clear from the analysis that projected benefits of individual links depend on the extents of cropping and irrigation that exist at present and the proposed cropping patterns in en-route command areas. If the proposed cropping patterns have substantial high-value crop areas, which at least give the net benefits as in fruits and vegetables, new investments on water supply in individual link commands are financially viable.

However, water transfers between links in the Mahanadi-Godavari-Pennar-Cauvery subcomponent are dependent on one another. Thus, it is more appropriate to assess benefits and costs for the whole component than for the individual links. When all links are considered together, the net value-added benefits still exceed the cost. The IRR and BCR are significantly higher than the discount rate (12 %) and 1 respectively, under Scenarios I and II; 19 and 1.7%, respectively, under Scenario III, and 15 and 1.3%, respectively, under Scenario IV. This shows that with proper cropping patterns, the aggregate net benefits of en-route commands in the Mahanadi-Godavari-Pennar-Cauvery component exceed the cost, and the investments are financially viable.

Does this mean that the subcomponent of linking Mahanadi, Godavari, Pennar and Krishna as a whole, is a financially viable investment? This is a difficult question to answer from the above results due to many reasons. We discuss these issues next.

Table 5. Share of water deliveries and contribution to net value-added benefits from domestic (DOM), industrial (IND), hydropower generation (HYP) and irrigation (IRR) sectors and net present value (NPV), benefit-cost ratio (BCR) and internal rate of return (IRR).

No. and name of link in Figure 1		Share of water deliveries (%)			Contribution to net value-added benefits (%).											
					Scenario 1				Scenario 2				Scenario 3			
		DOM	IND	IRR	DOM	IND	HYP	IRR	DOM	IND	HYP	IRR	DOM	IND	HYP	IRR
1	Mahanadi-Godavari	8	9	83	6	22	1	70	10	33	2	55	13	43	2	42
2	Godavari-Krishna (Nagarjunasagar)	6	8	86	4	14	0	82	na	na	na	na	na	na	na	na
3	Godavari-Krishna (Pulichintala)	4	6	90	1	5	0	93	2	9	0	89	3	12	1	84
4	Godavari-Krishna (Vijayawada)	10	0	90	4	0	0	96	6	0	0	94	14	0	0	86
7	Krishna (Nagar.)-Pennar (Somasila)	4	0	96	5	0	0	95	11	0	0	89	49	0	0	51
8	Pennar (Somasila)- Palar-Cauvery	15	12	73	4	10	0	86	5	12	0	83	7	16	0	77
9	Cauvery (Kattalai)-Vaigai-Gundar	5	10	85	1	4	0	95	2	9	0	89	3	15	0	82
16	Pamba-Achankvoil-Vaipar	0	0	100	0	0	30	70	0	0	45	55	0	0	69	31
	All links	8	7	85	3	8	0	88	5	13	0	81	8	21	1	71

Table 5 (continued)

Name and no. of link	Contribution (%)				NPV (US$), BCR (number) and IRR (%)											
	Scenario 4				Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	DOM	IND	HYP	IRR	NPV	BCR	IRR	NPV	BCR	IRR	NPV	BCR	IRR	NPV	BCR	IRR
Link 1	15	51	3	32	1,404	2.0	21	446	1.3	16	20	1.0	12	-201	0.9	10
Link 2	na	na	na	na	721	2.2	22	-674	na	na	-1,180	na	na	-1,464	na	na
Link 3	5	19	1	75	5,090	5.6	35	2,760	3.5	29	1,627	2.5	24	654	1.6	18
Link 4	15	0	0	85	1,348	3.9	30	917	3.0	26	88	1.2	14	64	1.1	14
Link 6	na	na	na	na	1,152	6.6	38	356	2.7	25	-85	0.6	5	-516	na	na
Link 7	7	17	0	75	5,867	5.0	34	4,491	4.1	31	2,964	3.0	27	2,605	2.8	25
Link 8	3	16	0	81	3,414	6.9	39	1,360	3.4	28	579	2.0	21	505	1.9	20
Link 10	0	0	96	4	156	1.3	16	-56	0.9	10	-195	0.6	5	-273	0.4	na
All links	10	27	1	62	19,360	4.3	32	9,844	2.7	25	4,084	1.7	19	1,653	1.3	15

Note: 1, "na" indicates values are negative or not defined; aggregate based on all links except Pamba-Achankvoil-Vaipar.

Sour ce: Authors' estimates.

Discussion and Conclusion

We discuss a few issues here that arise from our analysis of benefits and costs or from lack of detailed information on the proposed links.

- According to the NRLP plan, a substantial part of the proposed water transfers in the Mahanadi-Godavari-Pennar-Cauvery subcomponent is only a substitute for the water transfers out of the upstream of river basins. For example, 6,500 Mm^3 of water transfers in the Mahanadi-Godavari Link are allocated to meet the demand downstream of the Godavari River. If not for water transfers to Krishna from the upstream of Godavari, the above quantity for downstream use would anyway be available from the surplus water of Godavari. Since this quantity is only a substitution, what additional net output would this generate and account for the project benefits? A similar situation is applicable for the water transfers to the Krishna Delta through the Godavari (Polavaram)-Krishna (Vijayawada) Link, which amounts to another 3,500 Mm^3.

  The water transfers of these two links as substitution is 10,000 Mm^3, and this volume would be more than half the water delivered to en-route command areas. An important question here is whether the net value-added benefits from the water transfers as substitution are more than the value transfers can generate if they are new transfers to a region. Theoretically, this cannot generate any net value-added benefits in Godavari as it is a water-surplus basin. However, the water transfers to the Krishna Delta could add value as it is a water-scarce basin. However, it is not clear from the feasibility reports how this allocation would be used in the Krishna Delta.

  If the total capital cost of the Mahanadi-Godavari Link is added to the cost component, the IRR of all links under Scenarios III and IV will decrease to 13 and 10%, respectively.

- It is not completely clear whether the water transfers from Brahmaputra to Mahanadi basins through the Himalayan Links are necessary for the fully operational Mahanadi-Godavari-Krishna-Pennar subcomponent. If they are, then a part of the capital cost of the Himalayan Links should also be included in the peninsular subcomponent in this analysis. Therefore, the capital cost estimates of the links used in this study could be substantially lower, and hence the estimates of IRR and BCR could be higher. For instance, the Manas-Sankosch-Tista-Ganga, Ganga-Damodar-Subernarekha, and Subernarekha-Mahandi links in the Himalayan component facilitating water transfers from Brahmaputra to Mahanadi cost about US$19 billion. In fact, the total cost of these three links is 30% more than the total cost of the eight links in this study, and 200% more than the cost of water transfers to eight en-route link commands. Thus, adding a portion of the Himalayan component capital cost could very much escalate the total cost used in this analysis. Under such a scenario, the BCR and ICR will decrease drastically.

- A substantial part of the irrigation deliveries and the transmission losses in canals contribute to groundwater recharge. This recharge could help expand groundwater below the command areas and links. In this study, the extent of groundwater irrigation that will originate from this groundwater recharge and the resulting benefits are not clear. If these are known, it is certainly an indirect contribution for the benefit streams, and with regional multipliers the net value-added could be much higher. If we include these benefits, the BCR and IRR of the subcomponent could increase.

- The new reservoirs and canals will submerge large parts of forest and agricultural land and displace populations. Forests contribute to livelihoods of many people, especially the tribal population living there. They are the majority who will be displaced due to water transfers. The flora and fauna of the submerged lands were means of income for many people. This analysis has not considered the financial losses due to the submergence of lands, displacement of people and environmental impacts on the riverine environment. Such financial losses can decrease the net value-added benefits, reducing IRR and BCR.
- New reservoirs impound large quantities of water and affect the river flows downstream. Vladimir et al. (2008) show that many peninsular river basins could be perceived to have more surpluses than what they actually have. If these perceived surpluses are impounded and transferred out of the basin, they could badly affect river flows downstream. River flows in the downstream support the livelihoods of many people, especially in terms of inland navigation, fishing, tourism, etc. Thus, impounding could financially affect riverine populations directly and others indirectly. If these financial losses are included, IRR and BCR could decrease.

Our analysis indicates that if new water transfers only bring new lands into cultivation, the benefits are immense. Also, if water transfers are only used for irrigating the existing rain-fed lands, the net value-added benefits could still exceed costs by several factors. However, in reality this is not the case. The proposed command areas for irrigation in many river links already have some cropped areas and, in some cases, irrigated areas too. The financial viability of these links depends on the proposed cropping patterns. They require irrigating substantially high-value crops such as vegetables and fruits. The IRR and BCRs of links depend on many factors other than net value-added benefits of irrigation, domestic and industrial sectors in the en-route command areas and hydropower generation. These include hydrological factors related to groundwater recharge and benefits; environmental factors due to area submergence and loss of river flows, and social factors due to displacement, resettlement and rehabilitation of project-affected people. They need to be considered for a proper financial and social benefit-cost analysis framework.

Annex

Table 1. Changes in net irrigated area as a % of net sown area, and net groundwater irrigated area as % of net irrigated area in Andhra Pradesh and Tamil Nadu.

State and district		Net irrigated area - % of net sown area								Net groundwater irrigated area - % of net irrigated area							
		1971	1975	1980	1985	1990	1995	2000	2005	1971	1975	1980	1985	1990	1995	2000	2005
Andhra Pradesh	Adilabad	5	6	7	8	10	12	15	16	11	12	15	19	29	44	42	59
	Anantapur	13	15	14	14	15	14	14	11	38	45	48	56	59	68	71	70
	Chittoor	31	31	30	29	32	34	40	39	45	48	59	62	65	71	82	69
	Cuddapah	26	30	29	27	31	31	36	34	48	46	57	60	62	72	79	71
	East Godavari	63	64	65	64	62	63	65	65	4	7	7	11	10	17	20	21
	Guntur	48	50	54	57	58	54	59	59	2	4	4	4	6	9	11	15
	Karimnagar	22	29	32	40	60	68	69	76	47	46	50	46	52	66	62	56
	Khammam	16	20	21	30	39	40	42	42	14	10	18	15	21	26	29	37
	Krishna	64	66	66	72	72	68	68	66	6	6	7	7	8	11	12	16
	Kurnool	10	10	12	13	17	18	20	22	9	11	13	15	26	40	47	46
	Mahabubnagar	9	13	14	10	19	17	20	23	28	29	37	58	55	79	81	70
	Medak	15	20	22	23	31	27	30	29	22	27	42	48	54	77	87	80
	Nalgonda	20	28	27	27	35	38	40	46	18	18	26	25	37	47	53	53
	Nellore	62	64	69	74	81	82	76	77	16	21	26	30	28	32	37	36
	Nizamabad	34	46	47	49	59	59	67	70	12	12	19	22	37	67	68	72
	Prakasam	19	23	25	28	33	34	36	29	32	28	26	23	27	33	37	24
	Rangareddy	13	13	14	13	22	18	26	22	56	54	67	72	75	88	90	93
	Srikakulam	57	55	55	60	57	56	58	54	2	2	1	7	4	8	8	7
	Visakhapatnam	34	33	36	37	39	36	33	31	8	5	3	5	11	14	11	14
	Vizianagampuram	41	40	40	42	43	43	41	39	4	2	1	6	9	10	11	7
	Warangal	21	27	27	37	55	60	59	69	27	24	36	54	58	70	75	73
	West Godavari	75	77	77	81	81	82	82	83	16	17	20	21	25	34	37	39
Tamil Nadu	Chengaianna	72	76	81	82	73	81	86	85	18	28	37	48	50	53	52	61
	Coimbatore	36	40	47	42	41	47	55	52	50	55	56	56	50	55	59	56
	Kanyakumari	40	34	35	35	34	35	36	35	1	1	1	5	5	5	6	6
	Madurai	34	33	43	38	42	47	49	46	41	49	52	53	55	61	64	69
	North Arcot\ Ambedkar	50	48	46	48	39	50	56	56	49	52	65	66	86	70	78	80
	Ramanthapuram	37	40	41	37	40	41	47	43	15	17	19	25	26	26	28	26
	Salem	22	21	27	22	27	32	37	53	66	73	76	74	80	83	82	86
	South Arcot	50	57	59	51	50	55	63	90	34	45	53	50	65	67	67	70
	Tanjavur	83	84	83	84	84	78	88	65	2	2	2	3	8	5	3	7
	The Nilgris	1	0	1	1	1	1	2	2	0	30	15	22	6	7	6	6
	Tiruchirapalli	31	31	39	33	34	36	46	54	30	30	35	37	40	51	57	67
	Tirunelveli	34	33	40	37	39	44	44	41	39	41	39	43	39	42	44	44

Note: Highlighted rows are districts that include en-route command areas in this study.

Table 2. Cost of cultivation, crop yields and net value-added benefits/ha for different crops.

Factor and link name	Irrigated (IR) or rain-fed (RF) conditions	Crops							
		Rice	Maize	Other cereals	Pulses	Oil crops	Sugarcane	Fruits and vegetables	Cotton
Cost of cultivation ($/ha)	IR	439	268	257	337	329	628	748	381
	RF	195	183	227	81	310	628	505	77
Crop yield (tonnes/ha)									
Mahanadi-Godavari	IR	1.36	2.01	0.49	0.23	0.77	3.79	16.81	0.34
	RF	0.71	0.57	0.27	0.21	0.32	2.56	11.30	0.26
Godavari-Krishna	IR	2.60	4.00	1.36	0.57	1.21	4.85	17.30	0.34
	RF	1.50	2.43	0.44	0.39	0.56	3.15	11.49	0.28
Godavari (Inchampalli)-Krishna (Pulichintala)	IR	3.14	5.24	0.79	0.61	1.46	5.39	17.30	0.37
	RF	1.50	2.82	0.77	0.70	0.67	3.49	11.49	0.27
Polavaram-Vijayawada	IR	3.14	5.55		1.11	1.81	5.48	17.30	0.37
	RF		3.20	1.80	0.92	1.04	3.55	11.49	0.27
Krishna (Nagarjunasagar)-Pennar (Somasila)	IR	3.19	6.76	0.92	0.70	1.72	5.04	17.30	0.35
	RF		4.12	0.27	0.59	0.80	3.27	11.49	0.28
Pennar (Somasila)-Palar-Cauvery (Grand Anicut)	IR	3.27	1.87	3.06	0.54	1.71	7.52	16.56	0.38
	RF	1.98	2.55	1.68	0.61	0.85	2.80	8.43	0.27
Cauvery (Kattalai) -Vaigai-Gundar Link	IR	3.09	1.40	2.62	0.37	1.57	9.86	16.06	0.41
	RF	1.06	0.97	1.08	0.49	0.97	3.14	11.05	0.28
Pamba-Achankvoil-Vaipar Link	IR	3.55	1.31	3.07	0.37	1.44	10.57	15.54	0.38
	RF	1.00	0.80	1.61	0.51	0.95	3.14	10.68	0.23
Export price ($/tonne)		375	176	203	499	559	267	530	1,100
Net value-added benefits ($/ha)									
Mahanadi (Manibhadra)-Godavari (Dowlaiswaram)		1	170	14	-245	228	329	2,676	-214
Godavari (Inchampalli)-Krishna (Nagarjunasagar)		170	192	155	-166	346	455	2,838	-238
Godavari (Inchampalli)-Krishna (Pulichintala)		370	343	-26	-305	423	507	2,838	-199
Godavari (Polavaram)-Krishna (Vijayawada)		933	328	-396	-161	409	516	2,838	-196
Krishna (Nagarjunasagar)-Pennar (Somasila)		951	380	102	-201	499	473	2,838	-230
Pennar (Somasila)-Palar-Cauvery (Grand Anicut)		241	-204	249	-291	466	1,263	4,071	-191
Cauvery (Kattalai)-Vaigai-Gundar		515	-10	281	-316	321	2,009	2,418	-164
Pamba-Achankvoil-Vaipar		714	6		266	-328	257	2,198	2,332

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State of Irrigation in Tamil Nadu: Investments and Returns

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Introduction

Development of land infrastructure for agriculture in monsoonal Asia had three major phases of growth (Kikuchi et al. 2002). Bringing new land under cultivation for increasing agricultural output dominated the first phase. However, the cost of opening up new land increased gradually due to limitations of suitable arable land and constraints for developing them for agricultural activities. The response to this cost increase was development of irrigation on existing lands, which dominated the investments in the second phase. With increasing unit cost of new irrigation development, water management for agriculture became dominant in the third phase. At present, investments in the agriculture sector in Tamil Nadu are in the third phase, where improving the performance of existing irrigation facilities is the primary concern.

Trends in irrigation development show that the State of Tamil Nadu as a whole has already reached its irrigated potential. Most of the utilizable surface water resources for canal irrigation are stored in 64 large and medium, and 11 small reservoirs (GoTN 2007). Conventional potential developed with the available surface water resources in major and medium systems has reached a peak of about 1.5 million ha (Mha) in the 1970s (GoI 2006). More than 39,202 tanks support tank irrigation whose potential was reached long before 1970. The potential utilization of groundwater is more than 85% of the available resources (CGWB 2006). In fact, many regions in Tamil Nadu are experiencing severe groundwater depletion at present. Thus, maintaining the existing infrastructure and managing the distribution of surface water and abstraction of groundwater constitute the major focus in recent policy interventions and investment patterns (GoTN 2003).

However, in spite of significant investments in operation, maintenance and water management, especially in major, medium and tank irrigation sectors, the area under surface water irrigation has been decreasing in recent years. Moreover, in spite of vastly overexploited groundwater resources, private investments in groundwater development are increasing, albeit at a reduced pace (Amarasinghe et al. 2009).

This paper assesses recent trends in public and private investments, and their returns to agricultural production in Tamil Nadu. Such knowledge, with increasing water scarcities and demand, would be important to aid future investment decisions. First, we show the trends of public and private investments in the irrigation sector of Tamil Nadu since 1970. Next, we assess the contribution from different growth and investment patterns in irrigation to the state crop output. Third, we assess irrigation demand at present and potential water management improvements for meeting future demand. Finally, we conclude the paper with recommendations for investments in the irrigation sector to improve agricultural productivity and production.

Trends of Investments in Irrigation

Public investments, mainly on major, medium and minor irrigation schemes, meet the cost of new construction and rehabilitation, recurrent expenditure on operation and maintenance (O&M) and staff salaries and benefits. Major and medium irrigation reservoirs include schemes with commands over 10,000 ha and between 2,000 and 10,000 ha, respectively. Minor irrigation involves tanks; surface flow irrigation, which involves diversion from a stream or storage in a community-owned small tank or pond; and surface lift irrigation schemes, in which water is lifted from a stream or river into irrigation channels due to topographic constraints for direct surface flow irrigation.

Private investments are mainly in dug wells and in shallow and deep tube wells. Dug wells are open wells with a depth up to the water-bearing stratum. Shallow tube wells tap groundwater from the porous zones with a depth not exceeding 6-70 meters (m) and would, generally, operate about 6-8 hours and yield 100-300 m^3 per day during the irrigation season. Deep tube wells in general have a depth more than 100 m, discharge 100-200 m^3/hour, and can have 15 times more annual output than shallow wells. But the output is not sustainable (CGWB 2006; Palanisami et al. 2008).

Data on plan-wise investments in Tamil Nadu on major, medium and minor irrigation schemes were collected from various government publications for the study (GoTN 2007)

Public Investments in Major and Medium Irrigation Schemes

Public investments in major, medium and minor irrigation schemes from the first Five-Year Plan (1951-1956) to the tenth Five-Year Plan (2002-2007) are shown in Figure 1.[1] The investments in major and medium irrigation schemes show three different periods. First, the investments gradually increased to a peak in mid-1980, up to the sixth Plan. Almost all new constructions ended by that time. Since then, the investments have declined, along with net irrigated area, until the late 1990s. A major investment again in the eighth Plan has reversed and perhaps stabilized the declining trend in major/medium irrigation scheme areas.

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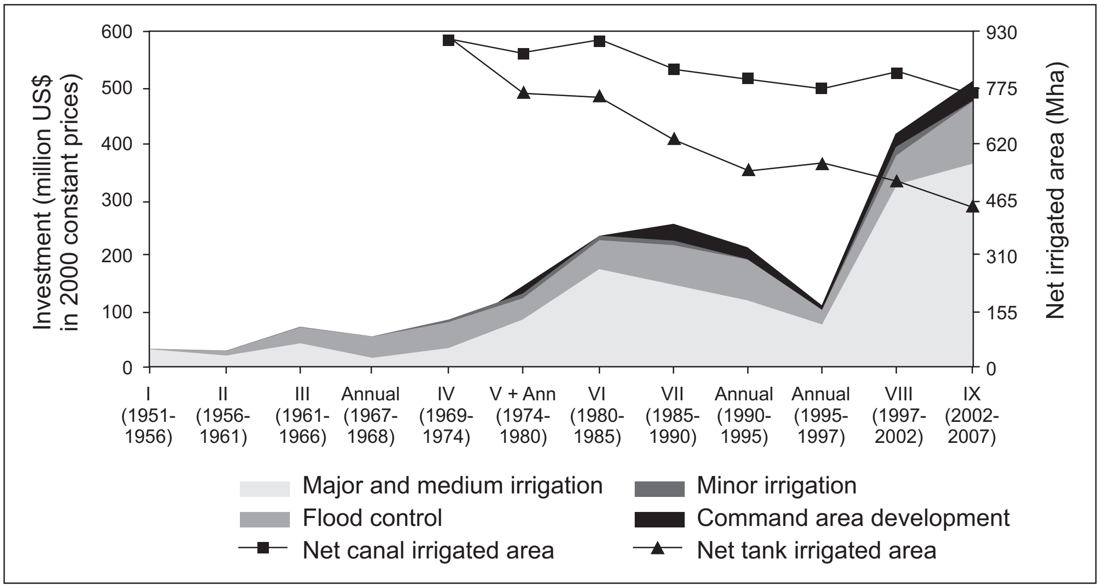
[1] This includes annual plans between 1967/68 and 1968/69, 1978/79 and 1980/81, and 1990/91 to 1996/97.

Figure 1. Public investments in major/medium and minor irrigation schemes.



Source: GoTN 2007.

The total expenditure in major/medium irrigation schemes was US$1,327 million (Rs 5,961 crores in 2000 constant prices) during 1970-2007. Indeed, a part of this public expenditure meets the salaries and benefits of the staff, amounting to 70-80% of the total annual recurrent expenditure. The annual expenditure on staff salaries and benefits in this sector is estimated to be around $16-18 million.[2] Thus, investments for rehabilitating and new construction of major/medium irrigation schemes in five-year plan periods since the mid-1970s could be well over $730 million. Yet, over this period, the net irrigated area under canals has declined by about 85,000 ha, or 10% from the level of the mid-1970s. This conforms to the all-India level marginal increase of 0.11 Mha per year during the 1990s compared to 0.22 Mha in the 1970s.

Regionally, the deltaic and central regions account for 53% and 32%, respectively, of the net irrigated area under major and medium irrigation schemes. Thus, it is assumed that these two regions benefited vastly from investments in major/medium irrigation schemes in the past few decades. However, the net canal irrigated area in deltaic and central regions has decreased by 50,000 and 10,000 ha, or 10% and 6%, between 1980 and 2000 (Amarasinghe et al. 2009). With increasing population and urbanization, the water demand in both domestic and industrial sectors will increase in the future. And, with higher income and affordability, the share of surface water supply for both sectors would likely be increased (Shah et al. 2008; Sundarajan et al. 2009). Thus, sustaining canal irrigation at the present level, especially in both the regions and generally in the state, will be a major challenge.

Public Investment in Minor Irrigation

***Tank irrigation*:** Minor irrigation has the next highest share of public investments, and a major part of it is spent on tanks. Tamil Nadu accounts for 17% of all tanks in India. As per official records, there are 39,202 tanks in the state. Most of these tanks are small and are linked to one another under cascading systems (Palanisami and Easter 2000; Gomathinayagam 2005). These tanks have inextricable links to the lives of the rural communities and are indispensable in sustaining village habitats and the socioecological balance. About 1.0 million rural households depend on the tank for their livelihoods and more than 75% of them are small and marginal farmers. Thus, O&M of tanks are important for the overall investment portfolio of the state water resources.

Tamil Nadu has initiated many tank rehabilitation programs in the past few decades, with several of them under the aegis of various external donors. They include the European Economic Community (EEC), Japan International Corporation Agency (JICA), National Bank for Agriculture and Rural Development (NABARD) and the World Bank. Since 1970, under the above programs, the state government has invested $430 million (Rs 1,940 crores in 2000 prices) in minor irrigation schemes, and a major part of this was on tanks. Of this, as much as $125 million[2] would have been spent on rehabilitation and new constructions of minor irrigation schemes. In tanks, these investments are mainly for physical rehabilitation and institutional interventions.

In spite of these regular investments, the net tank irrigated area has declined by more than 460,000 ha, or roughly 50% of the tank area of the 1970s (Figure 1). Many factors have contributed to the declining tank command area, including increasing variability of monsoonal rains, encroachment of supply channels and tank beds, sand mining of supply channels, rural infrastructural development such as roads and housing, and reduced tank inflows due to unplanned watershed development, etc. (Raj 2005). In several cases, the tanks have become defunct due to internal conflicts or due to no water inflows resulting from construction activities in the upstream of the tank catchment. The collection of water charge from the tanks has also declined due to nonfunctioning of the tanks, which are considered nonfunctional. In several cases, such tanks act as percolation ponds. However, not all of the area declined under net tank irrigation category has gone out of production.

In fact, groundwater irrigation is increasing in command areas in many small tanks. In the past, surface water from many small tanks was the source of irrigation in the respective command areas, and hence these areas were considered to be under the net tank irrigated command area. However, many small tanks are now primarily a catalyst for groundwater recharge (Palanisami 2008). This recharge is a reliable source for groundwater irrigation within the command area, and for the drinking water supply for the neighboring communities and livestock. Therefore, although many small tanks cease to support surface water irrigation, they still support irrigation indirectly through groundwater in command areas. These areas are now accounted for under the category of net groundwater irrigation.

Thus, although tank irrigated area is declining, maintenance of tanks in Tamil Nadu is still important. Some of them still directly support surface water irrigation, while many others, mainly small tanks, support groundwater irrigation. It is important to understand the threshold of the size of tanks, below which tanks mainly support groundwater recharge.

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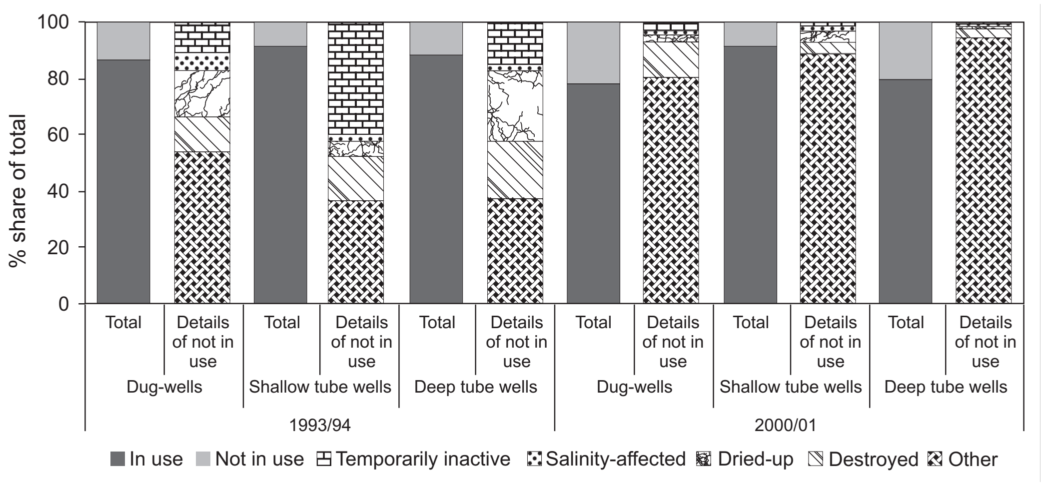
[2] The annual plans between 1990/01 and 1996/97 spent on average $14 ± 3 million (2000 constant prices) for minor irrigation. Salaries and benefits of this component, assuming 70-80% of the recurrent expenditure, are estimated to be about $10-11 million. So, overall investments in rehabilitating and construction of new minor irrigation since 1970 could be around $127 million.

Surface lift irrigation systems: Besides tanks, surface lift systems also create irrigation potential under minor irrigation. Surface lift systems mainly overcome topographic constraints by pumping water directly from streams or rivers to irrigation channels. These schemes, which are mainly public, are similar to river diversions, but often require large pumps, installed in the pump houses, to lift water from rivers. Some of them are government-authorized schemes and many operate under cooperative societies. Some of the schemes in the rivers are unauthorized and still pump water using diesel engines. The transaction cost of delivering the water is very high. Surface lift schemes provide irrigation to only 1% of the total irrigated area, and to less than 3% of the minor irrigation area in Tamil Nadu.

Private Investment

Private investments in irrigation are mainly on dug wells and tube wells. The second census of minor irrigation (MOWR 2001) shows that Tamil Nadu had more than 1.5 million dug wells, 107,661 shallow tube wells, and 36,462 deep tube wells by 1993/1994 (Annex Table 1). Of these, 13%, 8% and 11%, respectively, were not used in 1993/94 (Figure 2), and a substantial part of them were only temporarily inactive (57% of dug wells, and 37% each of shallow and deep tube wells). The permanent well failures, due to salinity, dried-up water supply, destruction or other reasons, were only 6% of dug wells and 5% and 7% of shallow and deep tube wells, respectively.

Figure 2. Wells (%) in use and the reasons for wells not in use.



Source: MOWR 2001, 2005.

The third census of minor irrigation conducted in 2000/01 shows that more than 150,000 dug wells, and 68,000 and 37,000 shallow and deep tube wells, respectively, were constructed over the 7 years since 1994 (MOWR 2005). In fact, construction of shallow wells and deep tube wells has increased substantially over this period, by 98% and 154%, respectively. However, annual growth rate of construction of tube wells is slowing down due to falling water tables. Although the number of inactive wells has increased between 1994 and 2001, the share of that in the total had decreased by 2001. In 2001, only 4%, 8% and 1% of dug wells, shallow wells and deep tube wells, respectively, were inactive. And more than 80% of them are only temporarily inactive.

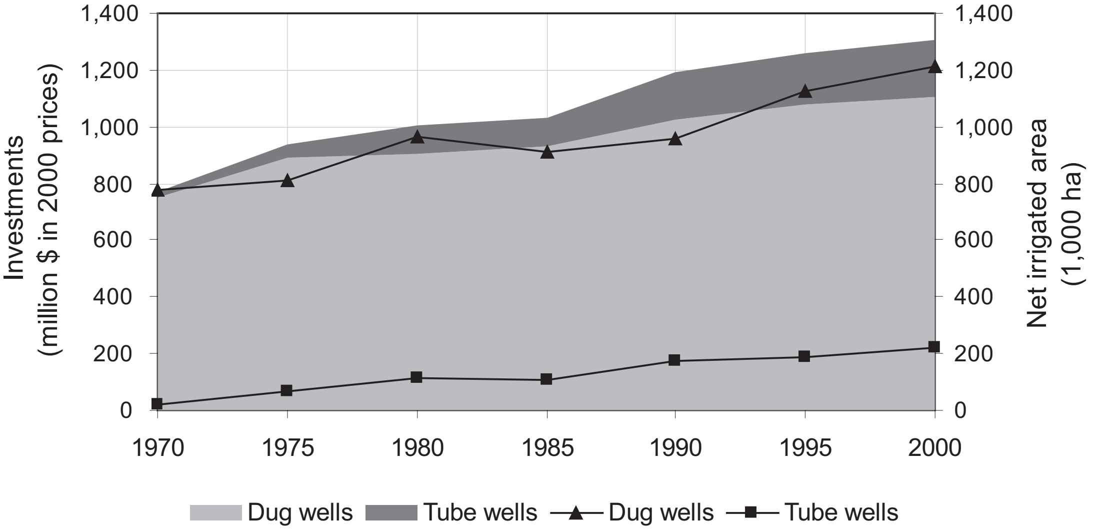
Due to extensive groundwater abstraction, the growth of dug-well construction has slowed down considerably in all regions. The central and southeast coastal regions have two-thirds of the dug wells, which had been constructed by 2000, followed by the north region with 17% (Table 1).

The growth rate of the construction of shallow tube wells has decreased in all regions except the north. But, the north region only accounts for a small share (less than 1%) of shallow tube wells. More than 85% of shallow tube wells are concentrated in the southeast coastal and deltaic regions, while the central region accounts for another 10%.

The construction of deep tube wells, however, has continued in most regions. The central region accounts for 46% of deep tube wells, followed by deltaic, north and southeast coastal regions with 18%, 14% and 10%, respectively. The growth rate of the construction of tube wells has decreased in the central and deltaic regions, while there are annual fluctuations in the growth rate in other regions.

No estimates of private investments, except the data on the number of wells, are available in official records. We estimate private investments in groundwater development[3] using the following assumptions. The construction of each dug well, shallow tube well and deep tube well costs[4] Rs 30,000, 50,000 and 100,000 (in 2000 prices; $1.00=Rs 44.94 in 2000), respectively. We also use the number of dug wells and tube wells per ha of net irrigated area (Table 1) in 1993 to estimate the total number of tube wells prior to 1993. Figure 2 shows these cost estimates along with data on the growth of net irrigated area.

Figure 2. Private investments in dug wells and tube wells.



Sources: Investments are authors' estimates. Area is from GoTN 2007.

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[3] Investment in electricity was a major driver of groundwater expansion in the state. By 1970, the peak demand of the state was 1,000 Mw. The demand has increased by 10 times to about 6,290 MW by 2000. Ideally, the part of the electricity consumption in the agriculture sector needs to be considered in the total investments in this sector.

[4] Indeed, the cost of construction varies between regions and also with other parameters such as depth, type of bore, etc. As these items of information for different regions are not available for this analysis; we use the same average cost per well in all regions for estimating the total construction cost.

Investments in dug wells:

- A large part of the construction of dug wells occurred prior to 1970. The aggregate investment in dug wells between 1970 and 2000 was about $357 million, which was only half of the total investment in dug-well construction before 1970 and 40% of the combined public investments (minus salaries and benefits) in major/medium and minor irrigation schemes since 1970.

- There has been a sharp decline in investments in dug wells in the last decade, accounting for only $66 million between 1994 and 1996, and only $16 million in the next 4 years.

- Regionally, central and northeast coastal regions account for 35% and 31%, respectively, of the dug wells constructed between 1970 and 200 while the north and southeastern coastal regions accounted for 17% and 12%, respectively.

Investments in tube wells:

- Most of the constructions in tube wells started after 1970. The total investment in tube wells between 1970 and 2000 was about $202 million, which was about ten times the investments before 1970, and only about 11% of the public investments in major, medium and minor irrigation schemes after 1980.

- About half the investments were on deep tube wells, and more than 60% of that were in the 1990s.

- Although, the investments in tube wells are increasing, the rate of growth is slowing down. This is especially true in the northeast coastal and deltaic regions, where more than 80% of groundwater resources are already utilized. Investments on tube wells in the north region show no signs of abating, although this region, as a whole, has overexploited its available resources.

- About 39% of shallow tube wells and 17% of deep tube wells were in the deltaic region, although this region only accounts for 8% of the net irrigated area under tube wells in Tamil Nadu. In fact, filter point wells account for about 69% of the wells in the deltaic region. This indicates that many of these wells in the deltaic region provide the necessary reliability of irrigation water deliveries in canal command areas. However, there is potential to increase the number of wells in the region.[5]

Next, we assess how these investment patterns have contributed to crop production in Tamil Nadu. We use gross value of output (GVOP) of crop production for this purpose.

Determinants of Growth of Gross Value of Output of Crops

The gross value of output (GVOP) consists of the value of production of 18 crops.[6] We use the average of unit export prices in 1999, 2000 and 2001 to estimate[7] the GVOP. It shows the change in gross production over time with respect to the changes in cropping patterns and productivity. The average export prices are used here only as a means for aggregating the crop production.

The GVOP of crops in Tamil Nadu increased steadily between 1970 and 1995 (Figure 3). The total crop output decreased slightly between 1995 and 2000, but decreased significantly after 2000, due primarily to severe droughts between 2002 and 2004. However, crop production seems to be picking up with good rainfall in recent years.

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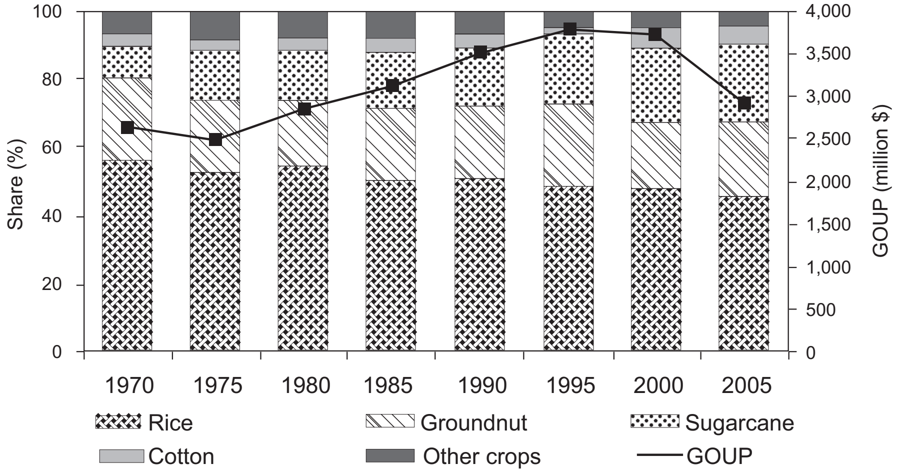
[5] Groundwater potential of the deltaic region

Groundwater potential of the deltaic region						Distribution of wells in the deltaic region			
Districts	Ground-water recharge	Utilizable ground-water recharge	Net ground-water	Balance	Develop-ment (%)	No. of wells possible	No. of bore wells	Number of filter points	Area covered (ha)
Tanjore	163,162	138,688	58,087	80,601	45	43,659	5,342	830	12,344
Nagapattinam	59,058	50,199	50,031	168	103	91	1,006	19,420	40,852
Trichy	222,305	189,384	98,461	90,923	55	49,253	6,405	8,758	30,326
Pudukottai	118,105	100,389	23,506	76,883	26	41,644	12,753	29,008	83,522

[6] These crops includes, rice (287), sorghum (97), pearl millet and finger millet (170), maize (108), wheat (123), chickpea (455), pigeon pea (231), groundnut (567), sesamum (691), rapseed/mustard (205), safflower (204), castor (384), linseed (329), sunflower (204), soybean (189), sugarcane (219) and cotton (1,150). The values within parentheses are the average of the unit export prices ($) in 1999, 2000 and 2001. Cotton prices are for cotton lint.

[7] $GVOP_t = \sum_{i=1}^{18} P_{it} \times average\,(p_i^{1999}, p_i^{2000}, p_i^{2001})$, where P_{it} is the production of i^{th} crop in t^{th} year, and $p_i^{1999}, p_i^{2000}, p_i^{2001}$ are the world export prices of i^{th} crop in 1999, 2000 and 2001, respectively.

Figure 3. Share of gross value of output (GVOP) by major crops.



Source: Authors' estimates.

Four crops, rice, sugarcane, groundnut and cotton, contribute to 95% of the crop output. The share of rice in gross crop production has decreased from 56% to 46% from 1970 to 2005 , while that of sugarcane has increased from 9% to 23%, and that of cotton has increased slightly from 3% to 6%. Among the other crops, maize had a major increase in crop production, accounting for only 1% in 1971 to 26% by 2005 of the gross output of other crops. In fact, maize production has increased by 16 times over this period to cater to the growing feed demand for livestock, especially for poultry.

Contribution from Irrigation to Crop Output in Tamil Nadu

The contribution from irrigation to crop productivity growth in India is well recognized. Irrigation is the key input that explains the vast differences of crop yields in neighboring irrigated and rain-fed areas (Huzzain 2005). With its ability to control water application, groundwater irrigation can have significantly higher crop yields than in other irrigated fields (Dhawan 1998; Kumar et al. 2008).

We estimate the contributions of different sources of water inputs, in terms of net irrigated and rain-fed areas, to crop output growth in Tamil Nadu between 1970 and 2000. The contribution from irrigation is further subdivided into different sources of irrigation, such as net irrigated area under canals, tanks, tube wells and dug wells. Along with irrigation, application of many other agronomic inputs, which has increased over time, has contributed to the growth of crop productivity. The information on total fertilizer use and area under high-yielding varieties (HYVs) of rice area is available for this analysis. Cropping intensity and crop diversification affect gross value of output. We estimate these effects in irrigated and rain-fed areas through aggregate indices (see Amarasinghe et al. 2009 for a detailed discussion). The use of many nonagronomic inputs, such as machines, transport, etc., also contributes to productivity growth. Increase in road infrastructure, which acts as a trigger for increasing many nonagronomic inputs, is available for this analysis. We estimate the contributions of different factors to gross value of output growth using a series of recursive panel regressions. The panels, consist of data in 10 districts over 31 years (1970-2000) and include

$$\begin{aligned} GVOP_{it} = \beta_0 + \sum_{i \in districts} \beta_{1i} D_{it} + \beta_2 NIA\_Canal_{it} + \beta_3 NIA\_Tank_{it} + \beta_4 NIA\_TW_{it} + \\ \beta_5 NIA\_DW_{it} + \beta_6 NRFA_{it} + \beta_7 CI\_IR_{it} + \beta_8 CI\_RF_{it} + \beta_9 CDIVI\_IR_{it} + \\ \beta_{10} CDIVI\_RF_{it} + \beta_{11} FERTT_{it} + \beta_{12} HYVRA_{it} + \beta_{13} ROADL_{it} + \\ \beta_{14} GOUP_{it-1} + \beta_{15} RF\_SWM_{it} + \beta_{16} RF\_NEM_{it} + e_{it} \end{aligned}$$

$$\begin{aligned} CI\_IR_{it} = \alpha_0 + \sum_{i \in districts} \alpha_{1i} D_{it} + \alpha_2 NIA\_Canal_{it} + \alpha_3 NIA\_Tank_{it} + \alpha_4 NIA\_TW_{it} + \\ \alpha_5 NIA\_DW_{it} + \alpha_6 CDIVI\_IR_{it} + \alpha_7 ROADL_{it} + \alpha_8 RF\_SWM_{it} + \\ \alpha_9 RF\_NEM_{it} + \alpha_{10} CI\_IR_{it-1} + \varepsilon_{it} \end{aligned}$$

$$\begin{aligned} CI\_RF_{it} = \gamma_0 + \sum_{i \in districts} \gamma_{1i} D_{it} + \gamma_2 NIA\_RF_{it} + \gamma_3 CDIVI\_RF_{it} + \gamma_4 ROADL_{it} + \\ \gamma_5 RF\_SWM_{it} + \gamma_6 RF\_NEM_{it} + \gamma_7 CI\_IR_{it-1} + \varepsilon_{it} \end{aligned}$$

$$\begin{aligned} FERTT_{it} = \eta_0 + \sum_{i \in districts} \eta_{1i} D_{it} + \eta_2 NIA\_Canal_{it} + \eta_3 NIA\_Tank_{it} + \eta_4 NIA\_TW_{it} + \\ \eta_5 NIA\_DW_{it} + \eta_6 NRFA_{it} + \eta_7 CI\_IR_{it} + \eta_8 CI\_RF_{it} + \eta_9 CDIVI\_IR_{it} + \\ \eta_{10} CDIVI\_RF_{it} + \eta_{11} ROADL_{it} + \eta_{12} RF\_SWM_{it} + \eta_{13} RF\_NEM_{it} + \\ \eta_{14} FERTT_{it-1} + \varepsilon_{it} \end{aligned}$$

where,

- Subscripts *i* and *t* vary over districts (10 in this analysis) and time (31 years from 1970,..,2000), respectively.
- $GVOP_{it}$ is the gross output of crops (in million $).
- D_{0i} are dummy variables taking value 1 for the ith district and 0 otherwise. We assume different intercept coefficients for districts in the panel regressions.
- NIA_Canal_{it}, NIA_Tank_{it}, NIA_TW_{it}, NIA_DW_{it}, are net irrigated area under canals. tanks, tube wells and dug wells; and $NRFA_{it}$ is the net rain-fed area (in 1,000 ha).
- CI_IR_{it} and CI_RF_{it} are cropping intensities[8] in irrigated and rain-fed areas.

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[8] In general, cropping intensity is defined as the ratio of gross cropped area to net sown area. However, this approach ignores the fact that some crops occupy the land in more than one season, and thus underestimates the cropping intensity. For instance, although sugarcane occupies the land throughout the year, its contribution to cropping intensity using the normal method is 100%, as both gross and net areas are the same. However, if rice occupies the same area and cropped twice a year, then cropping intensity is 200%. We eliminate this anomaly by taking the contribution of sugarcane, cotton and other non-food-grain crops, excluding oilseeds by multiplying the cropped area by a factor of 2, 1.6 and 1.5, respectively. That is, the cropping intensity in irrigated area is defined as s

$$CI\_IR = \frac{(IA\_grains + IA\_oilcrops + 2 * IA\_sugar + 1.6 * IA\_\cot ton + 1.5 * IA\_nongraincrops)}{NIA} * 100$$

where, IA_grains, IA_oilcrops, IA_sugarcane, IA_cotton, and IA_non-graincrops are annual irrigated areas under food grains, oilseeds, sugarcane, cotton, and other non-grain crops (mainly vegetables and fruits) respectively. Cropping intensity in rain-fed areas is defined using a similar method.

- $CDIVI\_IR_{it}$, and $CDIVI\_RF_{it}$ are crop diversification indices[9] of irrigated and rain-fed areas.
- $FERTT_{it}$ is the total fertilizer used (1,000 tons).
- $HYVRA_{it}$ is the total (HYV) rice area (1,000 ha).
- $ROADL_{it}$ is the total road length (1,000 km).
- RF_SWM_{it} is the actual southwest monsoonal rainfall (June-October).
- RF_NEM_{it} is the actual northeast monsoonal rainfall (November-April).
- e_{it} is the error term.

We estimate the coefficients using weighted least square regression with net sown area as weights. This eliminates the effects of heteroscedasticity. The estimated coefficients are given in Table 2. The contributions from different sources to the changes in GVOP over different time-periods are given in Table 3. We use the regression coefficients, which indicate the average growth in GOUP, to estimate the changes in contribution over different periods. The first regression results clearly indicate that irrigation had an enormous contribution to the increase in gross output of crops in Tamil Nadu. The contribution from irrigation alone to GOUP is about \$600/ha (\$894/ha of net irrigated area to \$292/ha of net rain-fed area).

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[9] Crop diversification in general expects to boost gross value of crop output. We capture the crop diversification using the following index, which is similar to the Theils index of inequality. Let the irrigated crop area of rice, maize, other cereals, pulses, oilseeds, sugar, cotton, and other non-food-grain crops as a percent of gross cropped area be defined as %IA_rice, %IA_maize, %IA_other, %IA_pulses, %IA_oilseed, %IA_sugar, %IA_cotton, and %IA_nongraincrops. Then the crop diversification index in irrigated areas is defined as

$$\begin{aligned} CDIV\_IR = (&\%IA\_rice^2 + \%IA\_maize^2 + \%IA\_otcer^2 + \%IA\_pulses^2 + \%IA\_oilseed^2 + \\ &\%IA\_sugar^2 + \%IA\_\cot ton^2 + \%IA\_ongrcr^2)*100 \end{aligned}$$

Crop diversification in rain-fed areas is defined similarly using the area under rain-fed crops. The index value of 100% shows the least crop diversification, indicating only one crop occupies the gross cropped area. The highest crop diversification occurs when gross crop area is equally divided among eight crop categories and indicated by the index value 12.5%.

Table 2. Estimated regression coefficients of gross output (GVOP in million $), cropping intensities in irrigated and rain-fed areas (CI_IR, Is this CI minus CI_RF in %), and total fertilizer use (FERT in 1,000 tonnes).

Variables	Estimated Coefficients (Coeff) and Standard error (SE) of estimates*									
	Gross output (GVOP) Regression 1		Gross output (GVOP) Regression 2		Cropping intensity in irrigated areas (CI_IR)		Cropping intensity in rain-fed areas (CI_RF)		Fertilizer use (FERT)	
	Coef	SE	Coef	SE	Coef	SE	Coef	SE	Coef	SE
Net irrigated area (1,000 ha)	0.864	0.10*	-	-	-	-	-	-	-	-
▪ Net canal irrigated area (1,000 ha)	-	-	1.052	0.23*	0.117	0.05*	-	-	0.114	0.05*
▪ Net tank irrigated area (1,000 ha)	-	-	0.761	0.17*	0.012	0.05	-	-	0.048	0.04
▪ Net tube-well irrigated area (1,000 ha)	-	-	1.232	0.25*	-0.127	0.06*	-	-	0.189	0.06*
▪ Net dug-well irrigated area (1,000 ha)	-	-	0.954	0.16*	-0.184	0.04*	-	-	-0.001	0.03
Net rain-fed area (1,000 ha)	0.262	0.07*	0.275	0.07*	-	-	0.154	0.04*	-0.005	0.02
Cropping intensity in irrigation (%)	0.569	0.21*	0.587	0.21*	-	-	-	-	0.060	0.05
Cropping intensity in rain-fed (%)	-0.090	0.09	-0.147	0.09	-	-	-	-	-0.022	0.02
Crop diversification in irrigated areas (%)	-1.504	0.49*	-1.171	0.53*	-0.238	0.14**	-	-	-0.181	0.12
Crop diversification in rain-fed areas (%)	-0.019	0.62	0.256	0.64	-	-	1.045	0.44*	0.309	0.15
Total fertilizer application (1,000 tonnes)	1.127	0.17*	1.025	0.19*	-	-	-	-	-	-
High-yielding rice area (1,000 ha)	0.247	0.09*	0.197	0.09*	-	-	-	-	-	-
Total road length (1,000 km)	2.586	0.81*	2.698	0.87*	0.400	0.19*	0.216	0.43*	0.864	0.20*
Southwest monsoonal rainfall	-0.024	0.03	-0.017	0.03	-0.009	0.01	0.003	0.02	0.008	0.01
Northeast monsoonal rainfall	0.005	0.01	0.006	0.01	0.004	0.00	0.004	0.01	0.010	0.00
Lag dependent variable of order 1 (Y_{t-1})	0.194	0.04*	0.172	0.05*	0.383	0.05*	0.206	0.06*	0.728	0.05*
R^2	89%		90%		63%		78%		92%	
Durbin Watson statistic	1.65		1.61		1.95		1.96		2.0	

Source: Authors' estimates.

Note: For brevity, coefficients of district dummies are not presented here. * and ** indicate that coefficients are statistically significant at 0.05 and 0.1 level.

Table 3. Contribution of different factors to the change in GVOUP in Tamil Nadu.

		Value (3-year averages)				Decadal change				Contribution from different factors to the change in GVOUP as a % of total estimated change			
Factor	Units	1970	1980	1990	2000	1970-1980	1980-1990	1990-2000	1970-2000	1970-1980	1980-1990	1990-2000	1970-2000
NIA-canals	1,000 ha	907	907	801	822	0	-106	20	-86	0	-48	6	-9
NIA-tanks	1,000 ha	911	752	544	518	-159	-208	-26	-392	-27	-62	-5	-27
NIA-tube wells	1,000 ha	20	114	173	218	94	59	45	198	27	29	14	23
NIA-dug wells	1,000 ha	778	963	959	1214	185	-4	255	436	33	-1	50	31
Net rain-fed area	1,000 ha	3,642	3,042	3,179	2,382	-600	137	-797	-1260	-37	15	-54	-31
CI_IR	%	142	144	144	138	2	0	-6	-4	0	0	-1	0
CI_RF	%	127	130	133	142	3	3	9	15	0	0	0	0
CDIVI_IR	%	51	46	39	39	-6	-7	-1	-13	1	3	0	1
CDIVI_RF	%	22	22	19	20	0	-3	1	-2	0	0	0	0
FERT_total	1,000 tonnes	296	519	807	975	222	289	167	678	48	107	40	59
HYVRA	1,000 ha	1,973	2,162	1,798	1,927	190	-364	129	-46	8	-26	6	-1
ROAD_length	1,000 km	61	118	175	207	56	58	31	145	32	57	20	33
Lag (GOUP)	Million $	2,510	2,922	3,351	3,958	412	429	606	1,448	15	27	24	21
GOUP	Million $	2,640	2,853	3,520	3,722	213	667	202	1,082	100	100	100	100

Notes: NIA denotes net irrigated area; CI_IR, CI_RF are cropping intensities in irrigated and rain-fed areas. CDIVI_IR, CDIV_RF are crop diversification indices in irrigated and rain-fed areas; HYVRA denotes high-yielding rice area; FERT is fertilizer use.

Source: Authors' estimates

Irrigation has also contributed to increased cropping intensity, crop diversification and input use. Thus, overall contribution of irrigation, directly or indirectly, to GVOP growth is more than the estimated direct contribution of $600/ha. The second regression, which estimates the contributions under different sources of irrigation, shows that:

- Canal and groundwater irrigation gives significantly higher outputs. The difference between canal irrigated and rain-fed areas is $777/ha, and the differences between tube well plus dug-well areas and rain-fed area are $957 and $679 /ha, respectively.
- Higher cropping intensities in irrigated areas also contribute to higher GVOP, with every 100% increase in cropping intensity in irrigated areas adding a further $587/ha to GVOP. With higher cropping intensities, the contributions to GVOP in canal irrigated areas are significantly higher.
- Crop diversification also had a significant positive impact on irrigated lands, where every 1% reduction in index, or increase in crop diversification, increases GVOP by $1.504 million. However, the contribution from diversification in rain-fed areas is not significant. The main reason for this difference is that irrigation assures the all-important reliable water supply for diversifying to high-value crops, while in rain-fed areas crop diversification is only a risk aversion for a total crop failure.
- Fertilizer application also has a significant impact, where every additional ton of fertilizer applied on gross cropped area increased GVOP by $1,205.
- Area under HYVs of rice also has a significant impact, adding $197 for every additional hectare.
- Infrastructural development also had a significanct effect in increasing crop output, with every kilometer addition to the road network having effected an increase of $2,698 in GVOP.

There are decadal changes in different factors and their contribution to GVOP increase in Tamil Nadu (Table 3). Between 1970 and 1980:

- Net canal irrigated area in Tamil Nadu had no significant change. Over this period, net area under tank irrigation and rain-fed area decreased by 17% and 16%, respectively. But, net groundwater irrigated area increased by 279,000 ha. A part of this groundwater irrigation expanded in areas previously considered under tank irrigation commands; also in several rain-fed farms farmers made new groundwater investments through drilling bore wells to avoid further uncertainty in rainfall.
- Total fertilizer application has increased by 75%, with an increase in their rate of application from 39 to 73 kg/ha.
- Total area under HYVs of rice has increased by 10%, while the coverage has increased from 75 to 85% of the total area.
- The length of the road network has expanded by 91%, with the road density increased from 4.7 to 9.0 km/ha.

The contributions from increased a) tube well and dug-well irrigated areas (27% and 33%, respectively), b) fertilizer and HYV use (48% and 8%, respectively) and c) road network (32%) have offset the production loss due to the reduction in tank irrigated and rain-fed areas

(27% and 37%, respectively). As far as irrigation is concerned, groundwater expansion has contributed significantly to increase crop production between 1970 and 1980.

Between 1980 and 1990:

- Net irrigated area under canals declined by 12%, while under tanks it further declined by 28%, which decreases are equivalent to a loss of 314,000 ha of net irrigated area from these two sources since 1980. However, over this period, net irrigated area under tube wells and rain-fed agriculture has increased by 52% (about 69,000 ha) and 15% (about 137,000 ha), respectively.
- With a 56% increase in total fertilizer application, the rate of fertilizer application has further increased from 73 to 113 kg/ha of gross cropped area.
- Total area under HYV rice has decreased by 17%, but high-yielding rice varieties covered 95% of the total area in 1990.
- The length of road network increased by 49%, resulting in an increase in the road density from 9.0 to 13.5 km/ha.

Contributions from increased area under tube wells, fertilizer application and expanded road infrastructure have offset the production losses in canal and tank irrigated areas. Increased fertilizer application had the largest contribution to GOUP increase. Once again, groundwater irrigation expansion offset the losses due to decreased tank and canal irrigated areas.

Between 1990 and 2000:

- Net irrigated area increased by 12%, from 2.492 to 2.787 Mha. Dug wells, (255,000 ha), tube wells (45,000 ha) and canals (20,000) have contributed to this increase. And, they offset the area declined under tank irrigation (25,000 ha) and rain-fed conditions (797,000 ha). Obviously, a part of the command area that declined under tank and rain-fed conditions is now irrigated under dug wells and tube wells.
- Total fertilizer use increased by 20%, with an increase in the rate of application from 117 to 157 kg/ha.
- Rice area under HYV increased by 7%, and almost all rice areas (97%) had been covered with HYV by 2000.
- Total road length increased by 17%, with increased road density from 13.5 to 15.9 km/ha.

Additional irrigation from groundwater and fertilizer application has contributed significantly to the increase in GVOP in this period. Although expanded road infrastructure contributed to GVOP increase, the magnitude is significantly lower than in the two previous decades.

Irrigation Investments and GVOP Increase

Clearly, a major part of the increases in GVOP in Tamil Nadu between 1970 and 2000 was due to private investments in dug wells and tube wells. The contribution from irrigation investments to the change in GVOP in Tamil Nadu between 1970 and 2000 is given in Table 4.

- A major portion of investments in major and medium irrigation schemes after 1970 was for rehabilitation and O&M of existing systems. In spite of close to $1 billion investments, net irrigated area under major and medium irrigation schemes decreased by 9%. And, that contributed to a 9% decrease in GVOP.
- In spite of continued investments in minor irrigation, tank irrigated area almost halved during this period. As a result, the contribution to GVOP decreased by 27%.
- However, investments in groundwater irrigation had a major positive contribution in increasing GVOP. Every dollar invested in tube well and dug-well irrigated areas added more than one dollar to GVOP over this period.

This analysis clearly shows the disproportionate returns to investments between surface water and groundwater irrigation in Tamil Nadu. The investments in surface-water irrigation in the 1980s and 1990s had twofold and threefold increases, respectively, compared to investments in the 1970s. Yet, there were no comparable gains in crop output over this period. In comparison, the investments in groundwater irrigation, although only 40% of the total investments in surface water irrigation, had a large impact in increasing crop output in Tamil Nadu between 1970 and 2000. This does not, however, mean that investments in O&M of canal irrigation and tanks were not useful. What is clearly required is a major overhaul in the pattern of public irrigation investments in Tamil Nadu. Some pertinent questions here are:

Table 4. Investments in irrigation, changes in net irrigated area and contributions to GVOP change between 1970 and 2000.

Scheme	Investments	Absolute and relative change in net cropped area (1,000 ha)		Contribution to change in GVOP and as a % of total change	
	(Million $ 2000 prices)	Million ha	%	(Million $ 2000 prices)	%
Major/medium irrigation	962	-86	9	-106	-9
Minor irrigation	368	-392	43	-321	-27
Tube-well irrigation	181	198	1,016	268	23
Dug well irrigation	357	436	56	368	31
Rain-fed agriculture	-	-1,260	35	-369	-31

Note: Although not included in the table, there were substantial investments for the watershed development program to assist rain-fed agriculture. (Please complete).

Source: Authors' estimates.

1. What investments in major/medium irrigation sector are required to maintain the schemes to irrigate crop area at the present level? It is a fact that major and medium reservoirs will end up in meeting the increasing demand in domestic and industrial sectors. It is unlikely that net irrigated area under major/medium irrigation schemes will increase in the future with the present level of water development. Therefore, crop production needs to be concentrated in high-productivity and high-potential canal irrigation schemes. Some important aspects that should be investigated here are:

    - Which major/medium irrigation schemes in different regions, or regions as a whole, will have a major competition for domestic and industrial water in the future?
    - Which major/medium irrigated areas have the highest productivity and income per every unit of water consumed?
    - What potential exists and what interventions are required to increase the productivity through crop or agricultural diversification?
    - What physical, institutional and policy interventions are required to spread water saving irrigation techniques such as sprinklers, drip system of rice intensification, aerobic rice, etc.?

These items of information will be necessary for identifying high productivity and high potential zones in major/medium irrigation command areas for crop production.

2. What minimum investments in minor irrigated areas are required to maintain surface-water irrigation in tank commands? It is obvious that in spite of large investments, tank irrigated area has been gradually decreasing. But the data indicate that groundwater irrigation may have replaced irrigation in many small tank command areas in recent times. Therefore, it is important to identify:

    - The tank irrigated commands with high crop productivity for sustaining crop production under surface water irrigation.
    - The small tanks that can be used for groundwater recharging to support groundwater irrigation in tank command areas (such as converting them into percolation tanks).
    - The institutional and policy arrangements required for maintaining tanks for groundwater irrigation in command areas, etc.

3. Where will investments in tube wells/dug wells generate high returns in the future? It is clear that, due to overexploitation of the available resources, new investments in tube wells and dug wells are gradually decreasing. The total investments in the 1980s were only 75% of the investments in the 1970s, and have since decreased to 49% in the 1990s. Because of overexploitation, further investments in tube wells and dug wells will only spread the water into a large area, but may not provide the adequate irrigation supply that the investment is required to provide. Thus, it is important to know:

    - What part of the total groundwater withdrawals is, in fact, depleted as consumptive water use and what investments are required to reduce overabstraction and improve the efficiency of groundwater use?
    - Which areas have high potential for further development? And what are the consequences of additional depletion in the downstream water use?

In the next section, we explore some of the questions that we posed above. There we estimate the total water withdrawals and consumptive water use in different regions, and develop scenarios to understand the implications of increased efficiency of water use.

Irrigation Demand

We estimate irrigation demand in 1999-2001 for 10 crops or crop categories (rice, maize, other cereals (including millet and sorghum), pulses, oilseeds, roots and tubers, vegetables, fruits, sugar, cotton and other crops) (See Amarasinghe et al. 2005, 2007a for more details).

Irrigation demand is estimated for both surface water and groundwater irrigated areas. We assume average project efficiencies of 35% for surface water and 55% for groundwater irrigation in 2000 (Amarasinghe et al 2007a). Table 5 shows the consumptive water use (CWU) of all crops, CWU of crops in irrigated areas, CWU in irrigated areas by irrigation, and irrigation demand in surface water and groundwater irrigated areas.

In 2000, Tamil Nadu depleted 29.4 km^3 as CWU in crop production. Of this, irrigated croplands depleted 23.7 km^3 or 80% of the total CWU. Irrigation deliveries contributed to 16.2 km^3, or 55% of the total CWU. The share of CWU in irrigated lands varies from 62% in the hill region to 94% in the deltaic region, and the share of CWU from irrigation varies from 45% in the north to 70% in the deltaic region. Although irrigated lands contribute to a large portion of CWU, the soil moisture due to rainfall still contributes to a substantial part of crop production. Improved rainwater management can still play a major role in crop productivity growth in many regions.

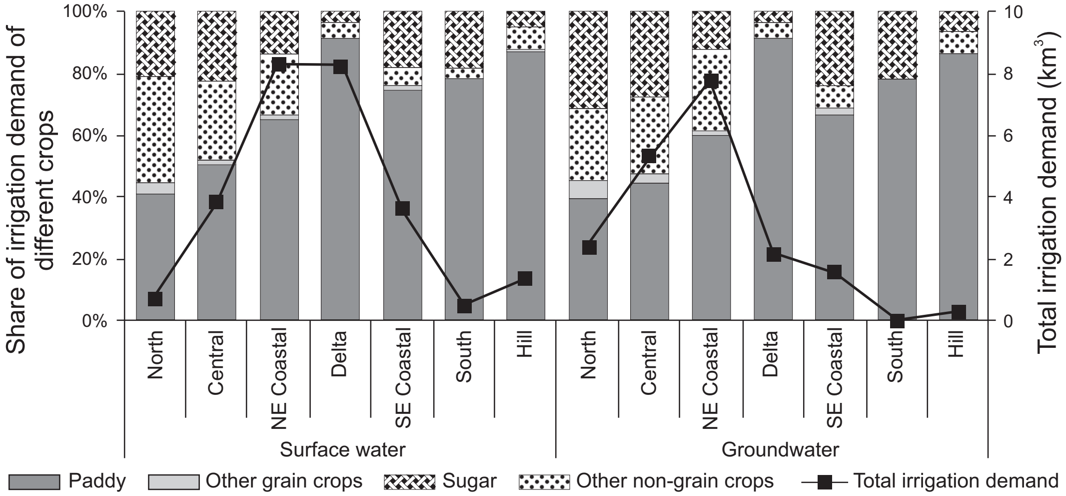
Irrigation demand, for a total irrigated area of 3.44 Mha was 46.3 km^3 in 2000. The northeast coastal, deltaic and central regions account for a large share of total irrigation demand, 35%, 23% and 20%, respectively. Of the total irrigation withdrawals, only 35% is depleted as CWU, indicating a large scope for reducing the irrigation demand by increasing irrigation efficiency. The opportunities for increasing efficiency are higher in surface water irrigation, accounting for 58% of the total irrigation withdrawals. This share in the deltaic and southeast coastal regions is much higher, accounting for 79% and 70%, respectively of the total irrigation demand. A large portion (73% withdrawals of surface water) is used for irrigating paddy (Figure 4). This share is more than 90% in the deltaic region.

Table 5. Consumptive water use and irrigation demand in 2000.

Region	CWS (in km^3)			Irrigation demand (in km^3)			CWU from irrigation as a % of	
	Total	In irrigated areas	Share from irrigation	Surface water	Ground-water	Total	Total CWU	Total irrigation demand
North	3.1	2.0	1.4	0.7	2.4	3.1	45	44
Central	7.3	5.4	3.6	3.8	5.3	9.2	49	39
NE coastal	10.4	9.0	5.9	8.3	7.9	16.2	57	37
Delta	4.4	4.1	3.1	8.3	2.1	10.4	70	29
SE coastal	2.8	2.3	1.6	3.6	1.6	5.2	58	32
South	0.3	0.2	0.1	0.5	0.0	0.5	40	25
Hill	1.1	0.7	0.5	1.4	0.3	1.7	43	28
Tamil Nadu	29.4	23.7	16.2	26.8	19.5	46.3	55	35

Source: Authors' estimates.

Figure 4. Surface water and groundwater irrigation demand for paddy, food grains, sugarcane and non-food-grain crops.



Source: Authors' estimation.

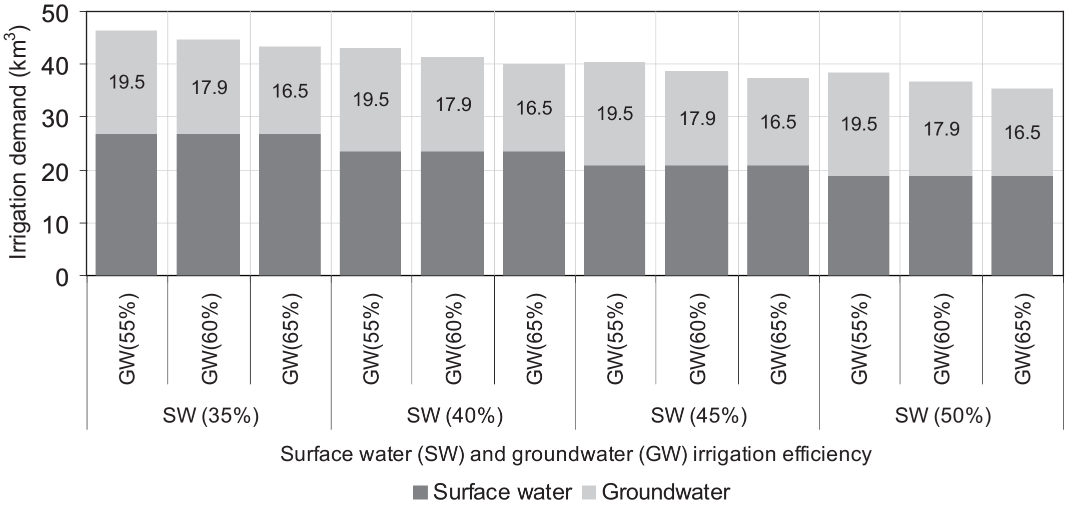
A major part of the total irrigation withdrawals in the southeast coastal, south and hill regions is also used for paddy irrigation, and these regions have very low CWU, accounting for only less than 30% of the total demand. Being located in the southern parts of the states, they have the largest scope for increasing irrigation efficiency without affecting the return flows and downstream users.

Groundwater is the source of 56% of the crop irrigated area, but it shares only 42% of the irrigation withdrawals. The north, central and northeast coastal regions account for 80% of the total groundwater withdrawals. These three regions, as well as the groundwater irrigated areas of other regions, have a significant area under non-food-grain crops, mostly dominated by sugarcane. The low ratio of consumptive water use at present, for instance 37%, 39% and 44%, respectively, in the north, central and northeast coastal regions (Table 5), shows that many groundwater irrigated areas do also have large scope for increasing efficiency, thereby reducing the pressure on scarce groundwater resources. To what extent can increasing irrigation efficiency save water in these regions? We show the benefits that can accrue using increased project efficiency scenarios in surface water and groundwater irrigation schemes.

Impact of Higher Irrigation Efficiency on Water Demand

Figure 5 shows the surface water and groundwater withdrawals under different efficiency scenarios: 35%, 40%, 45% and 50% for surface water, and 55%, 60% and 65% for groundwater irrigation.

Figure 5. Surface water and groundwater irrigation demand under different irrigation efficiency scenarios.



Source: Authors' estimation.

The current levels of surface water and groundwater irrigation efficiencies are 35% and 55%, respectively, and the total withdrawal at this level is estimated to be 46.3 km^3 (left-most bar in Figure 5). The differences between the first and the remaining bars show the reduction in irrigation withdrawals with improved irrigation efficiency scenarios.

If the groundwater irrigation efficiency is increased to 65% (third bar in Figure 5) the groundwater and total irrigation demand are 15% and 6% lower than the current level. If surface water irrigation efficiency is also increased simultaneously (say to 40%, sixth bar in Figure 5), then the surface water and groundwater irrigation demands are 15% and 12%, respectively, lesser than the current levels, and the total irrigation demand is 14% lesser than the current level.

If surface water and groundwater irrigation efficiencies can be increased to 50% and 65%, respectively, (last bar in Figure 5), then the surface water, groundwater and total irrigation demand can be decreased by 30%, 15% and 24%, respectively. Indeed, such irrigation efficiency improvements, which are not impossible to achieve under the current advances in technology, could have a large positive impact for water-scarce states like Tamil Nadu. The water saved by improving irrigation efficiency can then be used for either increasing production of the same crop, or to meet additional water demand for crop diversification, to meet increasing domestic and industrial demands, or to ecosystem water needs. We illustrate the potential benefits of the first two next.

Increasing Crop Production from Water Savings

In this, we illustrate the benefits only under the last scenario, where surface water and groundwater irrigation efficiencies are increased to 50% and 65%, respectively. Under this scenario, the total irrigation demand for maintaining the current level of crop production decreases by 24%. Paddy and sugarcane account for 84% of the total irrigation demand. Under the improved efficiency scenario, irrigation demand for paddy and sugarcane decreases by

25% and 22%, respectively. This increases water productivity--which is defined here as the ratio of irrigation production to irrigation withdrawals--of paddy and sugarcane by 33% and 29%, respectively (Table 6).

If all water savings in paddy are again used for paddy cultivation, the total production under the improved irrigation water productivity scenario could be 33% higher. Since almost all (97%) paddy production at present is under irrigation, the additional production with improved efficiencies would basically increase the overall rice production. Such increases would be more than enough to meet the rice demand of Tamil Nadu's increasing population in the short term. In fact, the total population in Tamil Nadu is projected to increase by 13% between 2001 and 2025, and then decrease by about 8% by 2050.

Table 6. Water productivity and savings in the cultivation of rice, maize, sugarcane and fruit crops under the improved efficiency scenario.

Region	Water productivity (kg/m^3 of irrigation water delivered)								Water savings under increased efficiency (km^3)			
	Under current level of efficiency[1]				Under increased efficiency[2]							
	Paddy	Maize	Sugar-cane	Fruits	Paddy	Maize	Sugar-cane	Fruits	Paddy	Maize	Sugar-cane	Fruits
North	0.32	0.41	0.36	1.13	0.39	0.49	0.46	1.37	0.23	0.00	0.16	0.04
Central	0.31	0.41	0.53	1.28	0.40	0.50	0.68	1.60	0.95	0.02	0.49	0.12
NE coastal	0.24	0.29	0.42	1.01	0.31	0.37	0.54	1.33	2.36	0.00	0.82	0.12
Delta	0.17	0.39	0.34	0.95	0.24	0.53	0.47	1.30	2.59	0.00	0.14	0.02
SE coastal	0.20	0.32	0.42	1.03	0.27	0.41	0.56	1.37	0.97	0.01	0.09	0.11
South	0.32			1.00	0.45			1.41	0.13	0.00	0.00	0.01
Hill	0.20	0.31	0.36	1.10	0.27	0.42	0.49	1.49	0.40	0.00	0.04	0.01
Tamil Nadu	0.23	0.39	0.44	1.12	0.30	0.48	0.57	1.43	7.64	0.03	1.74	0.43

[1] Current level of surface water and groundwater irrigation efficiencies are 35% and 55%, respectively.

[2] Improved level of surface water and groundwater irrigation efficiencies are 50% and 65%, respectively.

Source: Authors' estimation.

If the water savings in paddy are used for maize production, total maize production under the improved irrigation water productivity scenario could have a 28-fold increase. Although the current level of maize production is very small compared to paddy, it is the only food-grain crop that has recorded a significant growth of demand in recent times. Between 1995 and 2005, commensurate with increasing livestock feed demand, maize irrigated area and production had a fourfold increase. At the present rate of demand growth, maize production requires at least an 8-12-fold increase in the next two to three decades. Thus, most water savings through efficiency increase in paddy can be diverted to meet increasing demand for maize.

If water savings in sugarcane are again used for more of its cultivation, irrigated sugarcane production can be increased by 29%. As in paddy, all crop production at present is under irrigation. Thus, any additional production under irrigation will increase the total production with a similar rate of growth. Tamil Nadu produces significantly more sugar than it consumes now. And the present level of surplus is more than adequate to cater to the increasing population in the foreseeable future. Thus, the better option here is to divert the water savings in sugarcane irrigation to other non-food-grain crops.

If all water savings in sugarcane irrigation are used for fruit cultivation, additional fruit production could be 62% more than the total production at present, and the additional vegetable and cotton production could be, 126% and 269%, respectively, higher than the present production. Thus, as in the case of paddy, most water savings in sugarcane can be diverted to increase the production of fruits, vegetables and cotton. In fact, per capita demand of these crops has increased significantly over recent years and is likely to further increase with increasing income in the coming decades.

The above discussion primarily focused on the implications of crop production due to improvements in irrigation efficiency and water productivity. Increases in water productivity here are only due to a decrease in irrigation water use. But water productivity can also be increased by increasing crop yield. We discuss the implications of crop-yield growth on crop production and irrigation demand next.

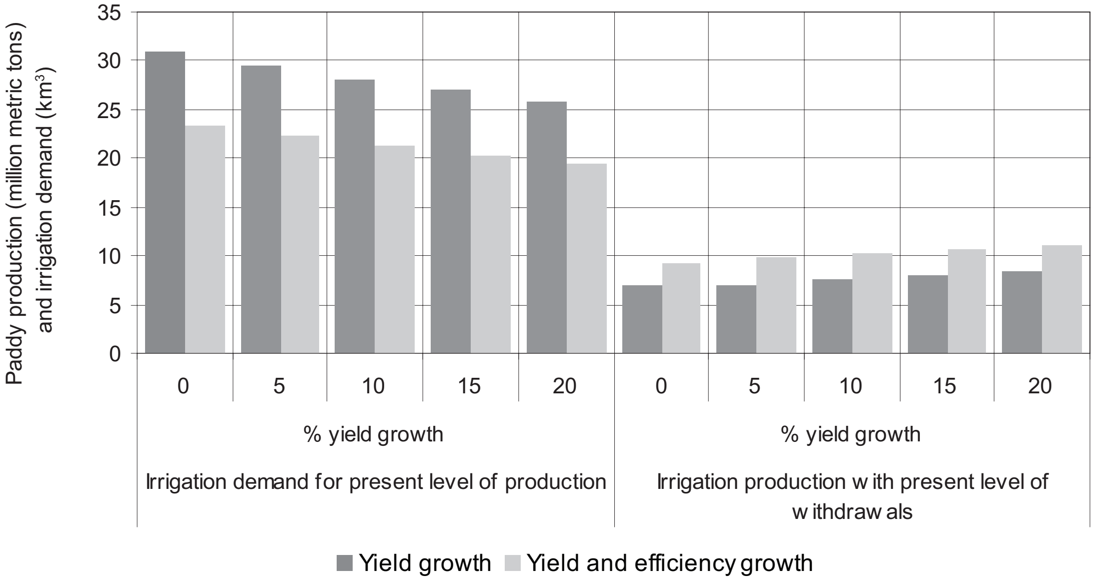
Impact of Higher Crop Yield on Irrigation Water Demand

Thanks to irrigation, yields of major crops in Tamil Nadu are comparatively better than those in most other major states. For instance, only Punjab (Indian part) has a slightly better rice yield (4.0 tonnes/ha) than Tamil Nadu (3.56 tonnes/ha). Sugarcane yield in Tamil Nadu is the highest, 12% higher than in Karnataka and 21% higher than in Maharashtra.

However, these yields in comparison to other major rice- and sugarcane-producing countries in Asia are still low. The average rice yields in China, the Republic of Korea and Turkey are more than 15% higher than those in Tamil Nadu. Yet, there could be an opportunity for increasing rice yield with better input management. In fact, Amarasinghe et al. (2009) show that the increase in paddy yield is significantly related to better fertilizer application, reliable irrigation input, and other technological advancements. We assess the implications of irrigated paddy production and irrigation demand, if irrigated yields are increased simultaneously with efficiency increase (Figure 6).

At present, the estimated irrigation demand for paddy is 31 km^3. If paddy yields can be increased by 10-20%, the irrigation withdrawals required to achieve the present level of paddy production will decrease by 9-17%. If irrigation efficiencies are also increased simultaneously, from 35% to 50% in surface water irrigation and from 55% to 65% in groundwater irrigation, then the irrigation demand for paddy would decrease by 31-37% from the present level.

Figure 6. Irrigated paddy production and irrigation demand under different scenarios of yield growth (0-20%) and irrigation efficiency growth (surface water efficiency is 35-50% and groundwater efficiency is 55-65%).



Source: Authors' estimation.

If paddy yield increases, then, barring any decline in area, production also increases at the same rate. But if the water savings through efficiency growth are again used for expanding paddy cultivation, then with a 10-20% yield growth, irrigated production can be increased by 39-53%.

This shows that a slight increase in crop yields and a moderate growth in irrigation efficiency can, in fact, decrease the irrigation demand for producing food for the increasing population. The total population of Tamil Nadu is projected to peak to about 71 million by the early 2030s, which is about 14% more than the 2001 level. So, essentially a similar increase in yield can meet the increasing demand for rice at the present level of per capita consumption.

But, in Tamil Nadu, per capita rice consumption is also decreasing at 0.69% and 0.39% annually in urban and rural areas, respectively; and a substantial difference exists in per capita rice consumption between urban and rural areas, 8.58-10.13 kg/month. Moreover, the urban population is increasing rapidly, 2.2% annually in the 1990s. So, with the present level of changing consumption and demographic patterns, the total rice demand could increase by only 6%, which is 8% points lesser than the population growth, by 2035. Thus, a yield increase of 6% is adequate to meet increasing demand for rice, and any simultaneous growth in efficiency can reduce the irrigation demand. In addition, interstate rice arrivals can also meet the local demand whenever the rice production decreases in the state due to failure of rains.

The above analysis clearly shows that a simultaneous increase in yield and irrigation efficiency can be a solution to the increasing water scarcities in Tamil Nadu.

Discussion and Conclusion

This analysis shows that major, medium and minor irrigation sectors in Tamil Nadu are not contributing to crop production growth exactly as the investments in these sectors are supposed to generate. Irrigation investments in these three sectors since 1970 have been primarily for rehabilitation and O&M of existing schemes, which could be well over \$1 billion. In spite of these investments, net surface-water irrigated area has declined between 1970 and 2000 by 10% in canal irrigation commands, and most notably by 50% in the tank irrigation commands. This indeed is a significant reduction, considering that 70% of the net irrigated area in the 1970s was under canals and tanks.

However, there is a strong possibility that not all the net area that declined from canal and tank irrigation has disappeared totally from crop production. A large part of the command area that was surface-water irrigated previously is now groundwater irrigated. This is more prevalent in command areas of small tanks, which are now acting as artificial groundwater recharge structures. Groundwater recharge is a source for reliable irrigation in a large part of surface water command areas, providing the much-needed domestic water supply for rural communities and livestock. Between 1970 and 2000, net groundwater irrigated area increased by 0.646 Mha compared to 1.719 Mha of area that declined under canal and tank irrigation and rain-fed agriculture. Over the same period, total investment in groundwater (dug wells and tube wells) irrigation development, which is mainly private, increased by \$560 million. This is only a little over half the public investments on surface-water irrigation schemes. Indeed, our estimate of investments in groundwater does not reflect the public investments in generating power, where the agriculture sector has enjoyed free electricity in Tamil Nadu since 1989 (Palanisami 2002).

In spite of the differences in investment patterns, it is clear that groundwater irrigation had a significant contribution for crop output increase. Between 1970 and 2000, the estimated contribution of groundwater irrigation alone to crop output increase is about \$636 million. In comparison, production losses due to area decline in surface-water irrigation and rain-fed sectors are estimated to be over \$795 million. Groundwater irrigation, not only as a reliable irrigation input by itself but also as a catalyst for other inputs such as fertilizers, has contributed to this production growth. In fact, contribution of increased fertilizer application to crop output growth was over \$695 million.

Groundwater irrigation could also have a significant impact on irrigation water use. In 2000, groundwater was the source for 56% of the 3.444 Mha gross irrigated area in Tamil Nadu. But, groundwater contributed to only 46% of the 46.3 km^3 of total irrigation withdrawals. A 10% increase in groundwater efficiency, from the present level of 50%, would reduce total groundwater demand by 15% and total irrigation demand by 6%. The Government of India has estimated that by increasing water use efficiency by 10% , it is possible to add an additional 14 Mha under irrigation (MoWR 2007). In the first place, such reductions would be a direct and enormous relief for groundwater-overexploited regions. Second, it can save the much-needed energy for other sectors, which the agriculture sector uses freely at present. If groundwater recharge from reservoirs and tanks can be effectively used for groundwater irrigation in command areas, it can improve crop productivity, increase efficiency, and save water for other sectors where demand increases with increasing population and economic activities

Increasing efficiency in surface-water irrigation is another way of meeting increasing water needs of the nonagriculture sectors. At present, surface-water irrigation is estimated to operate at 35% efficiency, and meets 58% of the total irrigation demand. A modest increase in surface-water irrigation efficiency, say by 15%, could reduce total irrigation demand by about 8.0 km^3. This saving, which is significantly more than the combined demand of 6.3 km^3 of the domestic and industrial sectors at present can meet the projected additional demand of 7.2 km^3 of these sectors by 2050 (Authors' estimates based on PODIUMSIM model; Amarasinghe et al. 2005, 2008). However, the impact of such improvements in surface-water irrigation efficiency on groundwater recharge and groundwater irrigation downstream needs better understanding

Another option is to use water savings through efficiency increases for increasing crop production. Improvements of surface water and groundwater irrigation efficiencies to 50% and 65%, respectively, from the present level of 35% and 50%, respectively, could reduce the irrigation demand by 24%. If water savings in paddy are again used for increasing paddy cultivation, additional rice production would be significantly more than the total additional demand for the increasing population. A similar production increase is possible for sugarcane, the most water-consuming crop in the state. In fact, only a part of water savings is adequate for irrigating other crops, such as fruits and vegetables for food and maize for livestock feeding. The demand for these crops is increasing with changing food consumption patterns.

Increasing crop yields on existing land can make additional irrigation demand less. For example, with the changing consumption patterns, total rice demand will increase anywhere between 6% and 14%. The latter is the growth of population of Tamil Nadu, when it reaches its maximum in the mid-2030s. Similar increases in crop yield on existing land would be sufficient to meet additional food demand without additional irrigation.

The future investments in irrigation in Tamil Nadu indeed require some rethinking. Investments in surface water irrigation would perhaps require new direction. Investments on O&M and rehabilitations of major and medium irrigation schemes are still required. More specifically, tertiary system improvements are needed for effective water control by the farmers (Palanisami et al. 2008). But investments should promote a different mode of irrigation within the command areas with a view to increase efficiency. This can include a properly managed conjunctive water use plan to utilize groundwater recharge in command areas, or intermediate storage tanks in a farm or in a group of farms for increasing on-farm water use (Amarasinghe et al. 2008). The latter can be a vehicle for spreading micro-irrigation in surface water irrigation commands.

Investments in tank irrigation require a completely new approach. Rehabilitation of tanks is still important, but the type of rehabilitation depends on whether tanks supply water for surface-water or conjunctive irrigation or whether the tanks recharge groundwater to facilitate complete groundwater irrigation in command areas. The threshold for selecting tanks only for groundwater recharge depends on its interconnectedness with other tanks in cascade systems and extents of water use in the neighboring communities, number of fillings and hydrogeology. Further research is required for selecting these thresholds. Selective tank modernization with needed interventions is recommended as against the package of modernization, which incorporates all components of tank systems (Palanisami and Easter 2000).

Groundwater irrigation is an important part of the irrigation landscape in Tamil Nadu, but overexploitation threatens its sustainability. Thus, public investment should facilitate groundwater recharge to augment water supply. Watershed development in overexploited regions for artificial recharge through dug wells needs to be taken up (Shah 2009). The state should explore policies and action plans for reducing groundwater overabstraction. As such about 19,330 micro-watersheds are delineated for interventions in the state and about 4,500 watersheds have been covered under the watershed programs. Increase in the water table due to watershed programs was ranging from 1 to 3 meters depending on the regions (Palanisami et al. 2009). Policy initiatives of pricing electricity, however, unpopular politically, can have an immediate impact, or providing separate reliable electricity supply for agriculture, such as Jothigram in Gujarat (Shah and Verma 2008) could be another option.

Irrigation investments should promote water saving techniques, such as drip and sprinklers, for reducing overabstraction. So far, Tamil Nadu has less than 20% irrigated area under drip and sprinkler irrigation. But water saving techniques can expand to a substantially more crop area (Narayanamoorthy 2009). Large-scale adoption of drip and sprinklers would not only save water but also improve irrigation efficiency and increase productivity.

Annex Table 1.

Year	Agroclimatic subregions					Tamil Nadu	Agroclimatic subregions					Tamil Nadu
	North	Central	Southeast coastal	Delta	Northeast coastal		North	Central	Southeast coastal	Delta	Northeast coastal	
	Number of dug wells						Number of dug well/ha of net irrigated area					
1993	265,902	548,611	466,500	28,848	182,215	1,533,839	1.19	1.41	1.28	3.5	1.52	1.39
1994	9,301	13,062	21,933	876	3,450	50161	1.12	1.30	1.31	3.6	1.48	1.34
1995	5,539	10,182	10,453	918	2,886	31528	1.14	1.52	1.32	3.0	1.77	1.44
1996	3,017	4,189	6,468	772	1,368	16549	1.62	1.48	1.27	5.6	1.91	1.53
1997	1,847	2,274	3,692	362	,804	9586	1.75	1.41	1.30	12.7	1.67	1.52
1998	992	1,648	2,403	247	483	5978	1.18	1.30	1.19	14.6	1.56	1.32
1999	620	1,075	1,053	95	412	3358	1.12	1.28	1.33	21.4	1.54	1.35
2000	766	807	1,918	33	928	5502	1.18	1.24	1.34	20.1	1.71	1.36
	Number of shallow tube wells						Number of tube wells/ha of net irrigated area[1]					
1993	718	11,083	54,314	38,920	1,555	107,661	1.36	1.19	0.43	3.25	1.72	0.78
1994	38	640	4,320	4,494	166	9,724	1.46	1.28	0.45	3.90	2.29	0.85
1995	28	921	3,789	4,466	181	9,503	1.55	1.59	0.46	4.86	2.71	0.93
1996	58	576	3,735	3,893	179	8,479	0.94	1.53	0.51	5.99	3.32	0.96
1997	125	667	2,618	3,227	191	6,944	1.25	1.67	0.49	4.99	2.46	0.98
1998	130	557	1,445	2,200	190	4,629	1.48	1.65	0.49	4.83	2.31	1.05
1999	95	470	706	1,374	128	2,809	1.41	1.67	0.50	6.13	2.66	1.06
2000	92	203	483	594	95	1,501	1.15	1.74	0.50	5.83	2.05	1.05
	Number of deep tube wells											
1993	6,136	15,218	4,827	7,441	767	36,462						
1994	907	2,359	681	1,833	148	6,532						
1995	557	4,254	467	1,600	160	8,044						
1996	782	4,686	560	1,493	165	8,518						
1997	789	3,596	386	1,034	179	7,194						
1998	658	4,319	833	890	272	8,188						
1999	1,380	2,561	409	660	247	5,978						
2000	301	1,581	229	496	99	3,094						

Source: Authors' estimates based on GoI 2009.

[1] This includes all shallow and deep tube wells per net irrigated area.

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Policy Interfacing and Irrigation Development in Tamil Nadu*

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Introduction

Irrigation is the lifeblood of agriculture, rural livelihood and food security in Tamil Nadu. Centuries-old tanks, and reservoirs and canals were the dominant features in irrigation till the mid-twentieth century. Irrigation landscape, however, began changing with private investments in minor irrigation, particularly in groundwater. Today, groundwater irrigation is becoming the cornerstone of providing water for agriculture, resulting in an overall exploitation rate of over 85% of the total available resources. Declining rates of tank and canal irrigation and overexploitation of groundwater are so critical that the state needs new policy interventions to tackle a pending water crisis. This policy brief recommends some development and investment options for the irrigated sector in Tamil Nadu.

Physical Features, Climate and Agroclimatic Zones

The state of Tamil Nadu, located at the southeastern extremity of the Indian peninsula, lies between 8° 5’ and 13° 35’ of the northern latitudes and between 76° 15’ and 80° 20’ of the eastern longitudes. Tamil Nadu has a coastal boundary of 922 kilometers (km) and a land boundary of 1,200 km, and its land area of 130,069 km^2 is bordered in the north by the states of Karnataka and Andhra Pradesh, in the east by the Bay of Bengal, in the south by the Indian Ocean, and in the west by the state of Kerala.

Geographically, the state has broadly two natural divisions: a) the coastal plains and b) the hilly eastern and western areas. It also extends a little in the Western Ghats in the Kanyakumari District. The Western Ghats, averaging 3,000 to 8,000 feet in height, run along the western part with the hill groups of Nilgiris and Anamalais on either side of them. The Western Ghats form a complete watershed and no river passes through them. The main streams in this side, namely Paraliyar, Vattassery Phazhayar, etc., are of limited length, and end up in the Arabian Sea. All major rivers are east-flowing. The Eastern Ghats are not a complete watershed containing all the watercourses within the state, and certain rivers pass across and

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*Based on the synthesis paper on State Irrigation Investment Strategies, presented at the State Planning Commission, Government of Tamil Nadu, Chennai on 12. 12. 2008. This synthesis paper, in turn, is based on the results discussed in the subsequent chapters and other research conducted by the IWMI-TATA water policy program.

beyond, notable among them being the Cauvery River, which is one of the main rivers. The tributaries of the Cauvery are Bhavani, Amaravathi and Noyyal. The other main rivers are Vaigai, Tamaraparani, Palar, Ponniyar and Vellar.

The climate of Tamil Nadu is basically tropical. Due to its proximity to the sea, the summer is less warm and the winter is less cold than other parts of Peninsular India. The maximum daily temperature rarely exceeds 40 °C and the minimum seldom falls below 15 °C. Both southwest and northeast monsoons influence rainfall in the state.

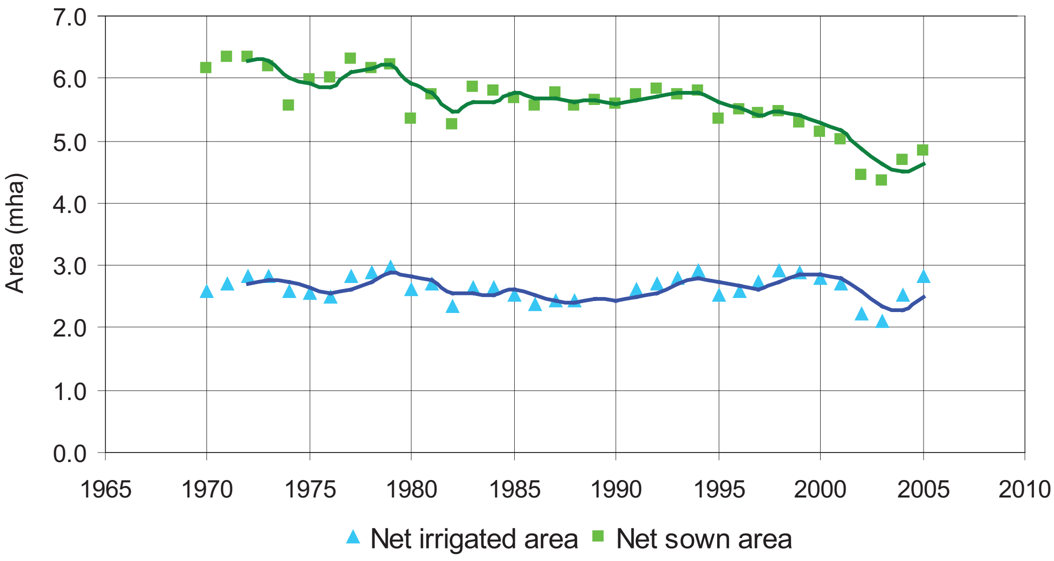
Based on rainfall distribution, soil characteristics and other physical, ecological and social characteristics, Tamil Nadu is classified into seven agroclimatic zones, namely northeastern, northwestern, western, Cauvery Delta, southern, high rainfall and hilly zones. The climate and the agroclimatic zones influence the water availability and use in different regions, in particular in the irrigated areas.

Trends of Irrigation in Tamil Nadu: 1971-2006

Net Sown Area

The net sown area in Tamil Nadu has had three distinct trend patterns over the last three-and-a-half decades (Figure 1). Overall, the total net sown area has declined by 25%, or 1.5 million ha (Mha), from 6.3 Mha in 1971 to 4.8 Mha in 2005. In the 1970s, the net sown area decreased at an annual rate of 0.77%. The declining trend stopped in the early 1980s, and remained steady until the mid-1990s. It started declining again at 2.1% annually after 1995.

Figure 1. Net sown and irrigated area in Tamil Nadu.



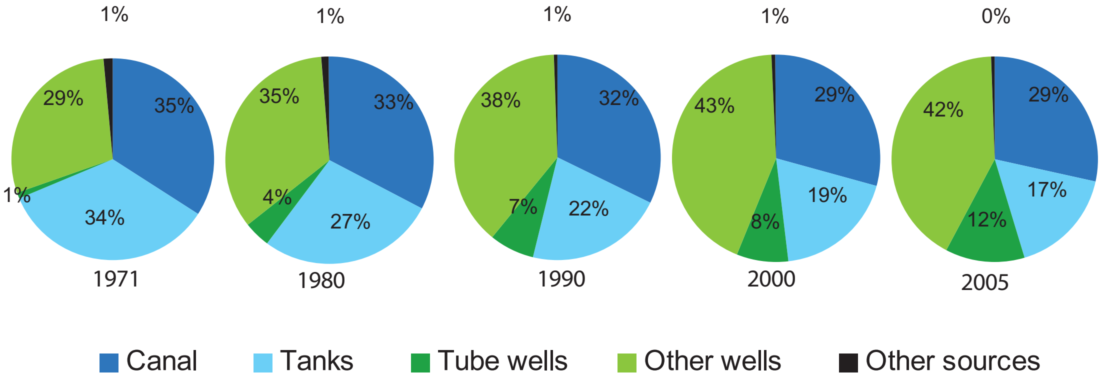
Net Irrigated Area

No significant trend in net irrigated area exists over the same period (1971 to 2005). However, with declining net sown area, the share of net irrigated area steadily increased from 42% in 1970 to 56% in 2005.

Contribution to Net Irrigation Area

The area under different sources of irrigation has changed drastically during the last three-and–a-half decades (Figure 2). Canals and tanks were the main sources of irrigation in the 1970s and 1980s, contributing to two-thirds of the total net irrigated area. But groundwater has dominated irrigation since the mid-1990s, and contributed to more than half the net irrigated area in 2005.

Figure 2. Land-use patterns in Tamil Nadu.



Canal Irrigation

Canal irrigation contributed to 34% of the total net irrigated area in the early 1970s. More than 140,000 ha were lost from the total net irrigated area under canals, and the current canal irrigated area accounts for 29% of the total net irrigated area in 2005.

Tank Irrigation

Tank irrigation contributed to more than one-third of the total net irrigated area in 1971, and had lost more than half of its net irrigated area by 2005. Although rainfall explains a significant part of the annual variation in tank irrigated area, there has been a consistent declining trend in tank irrigated area over the last few decades. Today, tank irrigated areas are only 17% of the total net irrigated area.

Groundwater Irrigation

Groundwater irrigation contributed only 30% to the net irrigated area in 1971. This share had increased to 54% by 2005. Groundwater expansion shows different growth patterns. First, it has replaced the area lost under surface irrigation, especially that under tank commands.

Second, it has spread well outside surface water command areas. Third, groundwater irrigation, especially through dug wells, seemed to be unsustainable in many regions. Dug wells were the main contributors to the growth of groundwater irrigation before the late 1990s. However, this contribution has been decreasing in recent years. Fourth, it is clear that reliance on tube wells in groundwater irrigation is increasing. In 1991, tube wells contributed to only 2% of groundwater irrigation. But this share had increased to 23% by 2005.

Gross Irrigated Area

Gross irrigated area has had a slight declining trend since the 1990s. This is primarily due to declining irrigation intensity. The irrigation intensity decreased from 130% in 1990 to 112% in 2005.

Given the trend in the irrigated area under different sources of irrigation, it is important to provide appropriate strategies to sustain the irrigation sector. Even though a vast array of recommendations is available through several research studies, the following measures could be considered and action initiated to manage the supply-demand gap in Tamil Nadu. The measures are grouped under “Policy Interventions” as follows:

Policy Interventions

Given the projection for 2050, the total water resources of the state including the potential interbasin transfers will be about 46,540 million cubic meters (Mm^3) compared to the total demand of 57,725 Mm^3 (i.e., agricultural demand of 49,978 and nonagricultural demand of 7,747 Mm^3). The projected supply-demand gap will be 11,185 Mm^3 (24%) (GoTN 2003). The gap will be further widened if the agreed interbasin transfers cannot be implemented and also if rainfall variability increases. Hence, it is important to address the needed policy interventions that may help bridge this gap for which the following are suggested.

Policy Interventions in Well Irrigation

The level of groundwater exploitation has been increasing over the years (Table 1). The number of critical blocks increased from 10.8% in 1987 to 46.2% in 1998.

Table 1**.** Level of groundwater extraction in Tamil Nadu.

Year of assessment	Total no. of blocks	Categorization of blocks (No.)		
		Critical	Semi-critical	Safe
1987	378	41	86	251
1992	384	89	86	200
1998	385	178	70	137

Extraction level: critical = 90-100%; semi-critical = 70-90%; safe = <70%.
Source: Director of Agriculture 2006.

In the case of electricity consumption in Tamil Nadu, out of the total pump sets (9.04 million), about 51.5% are accounted for by 5 HP electricity, followed by 7-10 HP pump sets (23.8%), indicating the need for protecting these regions from well failure due to overexploitation. Hence, it is important to identify appropriate strategies to manage the groundwater resources in the state.

Impact of Watershed Program

The watershed program has been implemented by different project implementing agencies, concentrating mainly on soil and water conservation and development of the rain-fed area. So far, about 4,000 micro-watersheds have been treated out of 19,240 in the state. As such, they account for about 10% of the area under rain-fed conditions and 1% of the area under wastelands. One of the major interventions is recharging the groundwater. According to the research studies conducted, rise in water levels varies from 3 to 7 m over the seasons (Palanisami and Sureshkumar 2005). On the basis of analysis of 358 watersheds, the following recommendations have been made.

Recommendations

- Intensify watershed developmental activities, especially in overexploited and critical blocks on a priority basis so that dysfunctionality of wells will be minimized. The abandoned wells should also be used for groundwater recharge.
- Water saving techniques, such as drip and sprinkler irrigation methods, should be introduced to all the commercial crops, and all the extension officers should be trained who, in turn, can train the farmers in the installation and maintenance of the systems. In addition, capacity building programs at the village level should be initiated to benefit all the farmers in the villages.
- A watershed program with recharging options should be implemented in areas with rainfall ranges of 700-1,000 mm/year.
- In tank-intensive regions, the focus of the program should be on soil and water conservation while in well-intensive regions, the focus should be on groundwater recharge.
- Combining five to six micro-watersheds will enhance the benefits of watershed programs.
- Wells in a zone of influence of 400 m (from the upstream of the water storage structures) should be accounted for while planning the water harvesting structures.
- Agricultural and livestock activities should be combined in all the watershed programs.
- A decision support system (DSS) incorporating the above options can be developed for each district and this DSS should be used for planning the watershed programs.
- Guidelines for post-project management of watershed programs should be developed for better management of watersheds.

Policy Interventions in Tank Irrigation

Tank irrigation systems in South India are centuries-old and they account for over 30% of the total irrigated area. According to the records, there are about 39,200 tanks in Tamil Nadu with varying sizes and types. Most of the tanks are mainly used to irrigate the rice crop from September to December. Several constraints limit the productivity of these tanks. Tank siltation, foreshore encroachment and poor maintenance of structures are major above-outlet problems; absence of water user associations (WUAs), a poor distribution system and inadequate groundwater supplies for supplemental irrigation are major below-outlet problems (Palanisami 2005). In three out of 10 years, the tanks get adequate storage (Table 2).

Table 2. Tank irrigation in Tamil Nadu in a 10-year period.

Tank storage	Storage level (%)	Probability[1]
Surplus	> 100	0.1
Full	70-100	0.2
Deficit	50-70	0.5
Very low	<50	0.2

[1]Based on 46 years' rainfall data.

Even though the number of tanks is about 39,200, it is not known how many are still functioning. The results of the study had indicated that in less-tank-intensive regions, about 64% of Public Works Department (PWD) tanks and 76% of the Panchayat Union (PU) tanks are defunct. In tank-intensive regions, about 2.6% of PWD tanks and 1.2% of PU tanks are defunct, showing that there is still a potential to make the tanks a better investment entity (Table 3).

Table 3. Tanks in Tamil Nadu: Functioning and defunct tanks.

Region/Tank type	Number of tanks		Mean command Area (ha)	
	PU	PWD	PU	PWD
Tank-intensive districts				
Total tanks counted	2,064	487		
Functioning tanks	2,039	474	12.67	105.2
(%)	98.8	97.4		
Defunct tanks	25	13	15.81	74.81
(%)	1.2	2.6		
Less-tank-intensive districts				
Total tanks counted	67	90		
Functioning tanks	16	32	22.48	79.75
(%)	23.9	35.6		
Defunct tanks	51	58	18.16	99.46
(%)	76.1	64.4		

Conversion of Tanks to Percolation Ponds

As rainfall has been varying much over the years, several tanks are functioning as percolation ponds, recharging the wells in the tank command. A partial budget was worked out using a 15-tank sample in the southern districts with the aim of comparing the financial gains and losses by cultivating paddy and sugarcane crops. Normally, a farmer with a command area under a tank with well conditions and having 2 ha land prefers to cultivate 1 ha each of paddy and sugarcane. The same farmer in the tank-only situation could cultivate only paddy in the 2 ha. Farmers with wells would be able to get a net income of about Rs 49,000/ha compared to those in other categories (Table 4).

Table 4. Value of production in tanks (using data from 15 tanks in southern Tamil Nadu).

Typology	Total value of production (Rs)	Total income (Rs/ha)	Additional income (Rs/ha)	Cost of cultivation (Rs/ha)	Net income (Rs/ha)	Additional net income (Rs/ha)
Tanks	2,344,490	28,343	0	17,589	10,754	0
Tank+ wells	13,049,154	71,406	43,063	38,719	32,687	21,933
Wells	2,656,928	106,582	78,238	57,505	49,076	38,322

Tank Sluice Rotation and Optimum Well Pumping

Currently, the tank sluices are continuously open and the tank water is exhausted within 6-8 weeks of the release of tank water. Hence, to keep the tank water available for a longer period and for wells to get recharged, tank sluices can be rotated alternately. By doing so, the tank water can be sustained for 10-12 weeks and groundwater supplementation assured to all farmers.

Well owners maximize profits from water sales when the water level is about 5 meters from the surface and this corresponds to about 5.6 hours of pumping per day from the well. Under these conditions, output of well water can best be increased by having farmers install more wells with increased competition. With more wells, the demand for water from each individual well will fall, resulting in a lower price for well water. According to a detailed survey, the number of wells can be increased by 25% in many tank command areas.

Tank Modernization and Its Impact

Tank modernization is one of the key strategies being recommended in all the policy documents. Even though tanks have been modernized through different programs in a small scale, a major program was implemented from 1984-85 to 1994-95, with financial aid from the European Economic Community (EEC). In the first phase (1984-91), 150 nonsystem tanks with a command area of 100-200 ha were selected for modernization with a financial outlay of Rs 450 million. In the second phase (1989-1995), an additional 230 tanks were included and in the same period, considered as Phase II extension, 269 tanks were included at a financial outlay of Rs 500 million. The approximate cost per hectare was Rs 21,000. The project was expected to save about 20% of water over the present use, thus permitting the expansion of cultivation by about 9,000 ha (PWD 1986).

There is no significant difference in the performance between modernized and non-modernized tanks in the region except marginal improvements in terms of water availability in tanks, reduction in encroachment, siltation, presence of WUAs and area covered by wells (Table 5). Since the EEC program was adopted, the package of modernization had the same modernization strategies for all tanks irrespective of their physical conditions. Hence, it is important to identify appropriate selective modernization strategies. Different tank modernization strategies have been examined which include sluice modification, provision of additional wells, sluice management and sluice rotation (Palanisami and Easter 2000).

Table 5. EEC tank modernization: Performance of EEC versus non-EEC tanks.

	Parameter	EEC tanks	Non-EEC tanks
1	Tank performance (%)	81.72	77.63
2	Filling pattern (no. of times)	1.36	1.28
3	Water availability (no. of days)	56.52	52.20
4	Siltation (%)	36.2	46.8
5	Presence of WUAs (%)	36.0	28.0
6	Farmers' participation (%)	40.0	42.0
7	Presence of Neerkatti (%)	68.0	64.0
8	Maintenance of tanks (%)	44.0	36.0
9	Farm income (Rs/acre)	6,240.0	5,975.0
10	Water management (%)	12.0	12.0
11	Equal water distribution (%)	40.0	38.0
12	Employment opportunity (man-days)	40.0	40.0
13	Cooperation among farmers (%)	44.0	40.0
14	Encroachment (%)	36.2	44.5
15	Area covered per well (ha)	9.0	11.0

Note: Based on a study of 50 tanks in the southern districts of Tamil Nadu.

Source: Palanisami et al. 2008.

Recommendations

- Wherever tanks receive less than 40% storages even in normal rainfall periods, they can be examined for their conversion into percolation ponds with encouragement for groundwater development. In other tanks with 40-70% storages, crop diversification should be encouraged with adequate market facilities and crop insurance programs.
- The conversion index of a tank-percolation pond should be developed. IWMI scientists will further work on this. Mostly rain-fed tanks with a lesser number of fillings should be considered while making the decisions on tank conversion.
- Tank farmers' associations should be strengthened and tank sluice management for water distribution practiced using the available groundwater supplies.
- Since the stabilization value of groundwater in tank systems is higher, it is always recommended to have an optimum number of wells in tank commands, such as one well per 2 ha in well-only situations, one well per 4 ha in tank-cum-well situations and one well per 10 ha in tank situations.
- The total number of wells in a tank command can be increased by 25%. Community wells should be encouraged to benefit the small and marginal farmers in the tank command and free electricity supplies should also be available to community wells for individual well owners to irrigate in the tank command.
- Partial desilting of tanks as a modernization option should be introduced and farmers encouraged to use the tank silt in their fields.

- Different revenue-generation options will help the tank management to be sustainable and hence such options in the tanks should be worked out.
- While implementing the watershed programs in tank-intensive regions, watershed structures in the tank foreshore should be avoided.

Policy Interventions in Canal Irrigation

Canal irrigation accounts for about one-third of the total irrigated area in the state. Three major areas of concern are:

1. How can inter-sectoral demand be met in the future?
2. How will water charges help support the subsidy calculations?
3. What are the future investment options?

Inter-sectoral Water Demand

The state water policy highlights the priorities in water allocation starting from the domestic sector onwards. It is expected that, wherever possible, the existing reservoirs have to meet the increasing domestic water demand and if so, then what is the impact of meeting this demand on irrigated agriculture? Keeping this in view, a detailed study was done in the Lower Bhavani Project (LBP) and Amaravathi (Reservoir Project [ARP]) areas to appraise the future water demand. Accordingly, in the LBP, nonagricultural demand will increase by 50% in the next 10 years and in the irrigation sector, water availability will decrease by 50% in dry seasons even though the wet season can manage the water shortages from canals (Table 6). The revenue generation also varies from domestic to irrigation sectors. Revenue from nonagriculture sectors will increase by Rs 319 million (30%) between 2010 and 2015, whereas the revenue from agriculture will decrease by Rs 131 million (9.2%) in the same period.

Table 6. Comparison of agricultural and nonagricultural demand in the Bhavani Basin.

Factors	2005	2010	2015
Water use (28.32 million m^3)			
Nonagriculture sectors	10.48	13.28	16.86
Agriculture sector			
Bhavani River	19.79	19.79	19.79
Lower Bhavani – Odd season	16.88	16.88	16.17
Lower Bhavani – Even season	8.11	4.39	0.62
Revenue generation (Rs million)			
Nonagriculture	819	1,063	1,382
Agriculture	1,522	1,422	1,291

Appropriate Irrigation Investment Options in Canals, Wells and Tanks

The internal rate of return (IRR) clearly indicates the rates of return for different investment types and it will be high for small system tanks (20.6%), followed by large system tanks (20.3%). In general, system tanks offer 19.8% return over the investment. Shallow tube wells within the surface command and dug wells within the surface water command have an IRR of 20.7% and 19.3%, respectively. The IRR to dug wells within the surface command will be 12.2%. Both watercourse and main system improvement will have 14.1 and 13.9% returns, compared to a 6.1% return over the investment on unimproved types. Similarly, improvement of watercourses could yield 13.4% followed by improvement of the main system (13.2 %) and unimproved types (6.2%) (Table 7).

Table 7. Financial evaluation of future investment strategies in Tamil Nadu.

Source	Benefit-cost ratio		IRR
	10%	15%	(%)
Reservoirs	0.77	0.58	6.1
Unimproved	0.77	0.59	6.1
Main system improvement	1.27	0.94	13.9
Water course improvement	1.28	0.95	14.1
Wells			
Dug wells	1.06	0.90	11.7
Within surface systems	1.46	1.10	19.3
Outside surface systems	0.76	0.57	6.0
Deep tube wells	0.96	0.75	8.1
Within surface systems	1.13	0.76	12.2
Outside surface systems	0.81	0.55	6.8
Shallow tube wells	1.37	1.13	18.0
Within surface systems	1.55	1.27	20.7
Outside surface systems	1.39	1.15	18.1
Tanks			
System tanks	1.49	1.22	19.8
Medium/large	1.52	1.25	20.3
Small	1.55	1.27	20.6
Nonsystem tanks	0.76	0.50	5.8
Medium/large	0.78	0.52	6.2
Small	0.80	0.52	6.4

Note: Surface systems refer to the reservoir and tank-irrigated command areas.

Recommendations

- Big reservoir systems have the advantage of new investment in watercourse improvements, and tanks will be benefited by investments in the main system improvements.
- In order to implement the water management strategies, investment in watercourse improvements should be given priority followed by secondary and main system management.
- Water harvesting plans for the Cauvery deltaic zone involving the existing and new tanks both in old and new deltas should be explored.

Water Management

Improved water management is one of the short-term strategies that can help save the irrigation water. About 10% saving in water would result in 14 Mha of additional area under irrigation (GOI 2006).

Current water use efficiency:
Canals: 35-45%; tanks: 30-50%; wells: 40-65%

Given the scope of introducing water management technologies in canals, tanks and wells, it is possible to save about 919 ha.cm, i.e., 20% of the total water supply (Table 8).

Table 8. Possible water savings in major crops.

Crop	Gross area irrigated (000 ha)	Present water use (000 ha.m)	Water reduction possible (%)	Total saving ('000 ha.m)
Rice	2,107	3,160	25	790
Sugarcane	283	566	17	96
Cotton	80	48	15	7
Groundnut	270	121	15	18
With drip/sprinkler	20	32	25	8
Total				0.92 M.ha.m or 325 Bcf

M.ha.m = million hectare meters; Bcf = billion cubic feet; 1 M.ha.m = 353.26 Bcf; 1 Mm^3= 0.0353 Bcf.

The reuse of wastewater is important. The sewage generated from river basins indicates that about 730 Mm^3 can be reused, assuming that 75% of water supplied to the urban population returns as sewage and 90% of it can be reused. This means about 67% of domestic water demand can be reused in the future (GOTN 2003).

Recommendations

- Transfer of water management technology and upkeep options should be given top priority in investment plans. Types of technologies suitable for different crops and regions in the future should be prepared covering the state as a whole. Also capacity-building aspects should be strengthened at various levels.
- Analysis of constraints in technology adoption and the required strategies for upscaling them should be assessed.
- Implement a focused capacity building program involving the drip farmers in further upscaling drip irrigation and other related management strategies.
- The cost of wastewater treatment and transaction cost for delivery to different locations should be worked out and compared with alternative sources of supply.

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Institutional Vacuum in Sardar-Sarovar Project: Framing ‘Rules-of-the-Game’

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Abstract

Few large irrigation projects in India have been as elaborately planned as the Sardar-Sarovar Project (SSP), incorporating as it did the lessons of decades of irrigation project design and management. The project was to blaze a new trail in farmer-participatory irrigation project design and management with water user associations (WUAs) building their own distribution systems. However, as it unfolds, the institutional reality of the project is seen to be vastly different from its plans. If SSP is to chart a different course from scores of earlier large irrigation projects, it must invent and put into place new rules of the irrigation management game.

Backdrop

With 30 years in planning, over 15 years in construction and some Rs 1,500 billion of investment later, the saga of SSP’s vision is now ready to unfold. When fully commissioned, the project will use 5,600 km of main and branch canals and 66,000 km of distribution networks (including distributaries and minors) to deliver 9.8 km^3 of irrigation water to 1.8 million hectares (Mha) of land. Besides, SSP is also expected to boost the rural and urban drinking water needs of the state and also help recharge groundwater aquifers in intensively groundwater-irrigated areas of North Gujarat and Saurashtra. If all these targets are fully or even substantially met, SSP will indeed prove to be the lifeline of Gujarat. And this will happen if its operational strategy, i.e., key assumptions made during the planning phase about its manner of operation, holds. The operational strategy of SSP was to be put to test in *rabi* (October to March) 2002. The key elements of this strategy are:

1. The project will create distribution infrastructure such that each village has one or more *pucca* (lined) minors depending upon its culturable command area (CCA); the distribution system below the minor, including lined sub-minors, delivering water to 40-60 ha *chaks* (small command areas), and field channels further down to serve 5-8 ha sub-chaks, will be created by the irrigation community; the thinking was presumably that, by involving the irrigation community in the design and creation of distribution infrastructure below the minor, the project would not only invite genuine partnership with the community but also provide an organizing logic for the WUA.

2. The irrigation community in each minor (serving a Village Service Area [VSA]) will form a WUA whose responsibility will be to: (a) mobilize community labor and resources to create the water distribution system below the minor; (b) arrange orderly distribution of irrigation water within the command; (c) ensure future maintenance and upkeep of the distribution system below the minor while the canal infrastructure up to the minor level is maintained and operated by the SSP; (d) collect water fees at Rs 157/irrigation/ha, of which Rs 7 would go back to the WUA as a subsidy to meet administrative expenses. The idea was that participatory irrigation management (PIM) in the SSP starts at the beginning, rather than come up midstream when system managers have taken all crucial design decisions.
3. The project will provide only 21 inches of irrigation requirement in five irrigations turns during rabi; no summer irrigation was envisaged, nor was it envisaged that Narmada water would be used to raise perennial, water-intensive crops like sugarcane and banana; the SSP planners' idea was to cover large areas through extensive irrigation rather than supporting a small, intensively irrigated command. The logic of rationing water was to stem at the outset the propensity for early command areas at the head of the system to form the habit of practicing water-intensive agriculture.
4. The SSP's primary responsibility was to be the upkeep of the infrastructure up to the minor level, and timely delivery of water on a volumetric basis to each VSA through the WUA which would collect and aggregate indents from individual farmers in the command. That done, it was expected that the WUAs would take over the responsibility of water distribution with the VSA. The SSP would not consider water indents by individual farmers unless these are routed through the WUA. This was expected to result in division of O&M responsibility and costs in which the project takes the responsibility of those parts of O&M that require technical and engineering competence of a high order whereas WUAs will operate and maintain local infrastructure within the VSA where the knowledge of local conditions is critical.
5. The system is planned for sophisticated, computerized water control from control rooms strewn along branches and distributaries throughout the command; while the control rooms are ready, the water control infrastructure will take a long time to install and commission. As a result, for several years, volumetric water control will be operated manually, if at all. The basic idea is to introduce volumetric delivery and charge at all levels from the very beginning

As visions and strategies go, the early years of the operation of the SSP will be critical; they will decide whether the project will run according to the original vision outlined above, or by a new evolutionary operational framework even superior to the original vision, or regress into an operational mode in which the SSP will follow in the footsteps of other major irrigation projects, where achievements on all counts have fallen far short of expectations.

Running-in

The SSP is now poised at that crucial juncture. Like a new engine being run in, the SSP too is getting ready to be 'run in.' Starting in rabi 2002, SSP has begun to release irrigation to some 80,000 ha of its command in Narmada, Bharuch and Vadodara districts where canal and distribution infrastructure up to the minor level is fully or partially ready. While the full reservoir capacity is likely to be created once the dam height is raised to 135 m, it will take 10-15 years before the canal network gets constructed to cover the entire command area of the project. Until then, SSP will gradually evolve, adding new areas in its irrigated command every year. In this process of evolution, the experience of these formative years will prove decisive in three ways: (a) system managers as well as users' behavior and practices in the first years will take the shape of habits, which will be difficult and painful to change later; (b) the behavior, practices and habits allowed to form in the early parts of the command will define the norms, rules, behavior and habits in new areas being brought under the command as the project evolves; and (c) early years will decide whether the actual operational framework of the project is faithful to the original vision or whether it is superior to, comparable with or inferior to it.

Members of the SSP field staff have already done some amount of WUA organizing work in the 800 villages encompassing the first year command of 80,000 ha. Typically, a group of 11 leading, forward-looking farmers, generally representing all or most of the chaks constituting the command area in each minor (sometimes, more than one minor) are formed into a management committee of the WUA who also act as promoters, with one of the members nominated as (often cajoled to become) the president. Over 800 WUAs have been registered as cooperatives under the Co-operative Act. However, registering WUAs as cooperatives is quite different from catalyzing functional WUAs that begin to undertake all the tasks they are expected to perform. The critical challenge facing the SSP is to activate and energize the 800 odd minor-level WUAs so that they begin to play the role envisaged for them by the SSP vision.

Impressions from Fieldwork

During late 2002, IWMI-Tata researchers worked together with the field staff and engineers of the SSP to develop a firsthand assessment of the preparedness of the irrigation communities to receive and utilize Narmada water for irrigation. Some 40 villages in different parts of the command were covered. Subsequently, IWMI-Tata Program continued with field surveys and studies in these villages. The objectives of this field research were:

1. To develop a quick situation analysis of the conditions in each village covered including the size of the farmlands, number of irrigators, socioeconomic structure, cropping pattern, existing irrigation sources, farm productivity, etc.
2. To assess the preparedness of the irrigation groups to receive Narmada water and arrange for their orderly distribution.
3. To assess the level of user comfort with the SSP water pricing (which is higher compared to government water pricing in all other surface irrigation systems) and the mode of collection of water fees and their reimbursement to the SSP.
4. To understand the general state of the WUA, its internal dynamics, public awareness about its existence, functions and future role.
5. To develop an assessment of the likelihood of the role of the SSP vision, outlined earlier, being played out in reality; and to develop a prognosis of what might happen if it does not.

The general situation in the 40 villages covered by our fieldwork was highly variable. Some villages near the Kevadia Colony, near the head of the system, have had a small area irrigated by Narmada water on a trial basis; some more area in the Bharuch District too received some surface irrigation from small and medium irrigation projects, such as the Deo project. Barring these small patches, the entire area commanded in this first phase has never seen canal irrigation before. However, we found that even villages which had some canal irrigation experience had no experience of farmer management of water distribution. In Devalia and Madhodar minors, where the sub-minors too were constructed by the SSP Nigam under a pilot project, WUAs were formed some 3 years back and were supposed to manage water distribution and water fee collection. However, in reality, the water rotation roster is given to them by the Nigam officials and the WUA has done little of its own rule-making work. Moreover, whereas in Mahi and Ukai-Kakrapar commands we found vibrant farmer organizations (FOs) like dairy and sugar cooperatives, the villages we visited in the SSP command had virtually no experience in successful FOs at the local level. If anything, people had bitter memories of all manner of cooperatives that had either swindled them or become defunct.

Groundwater irrigation was fairly well developed in some parts but absent in other areas, such as in Bharuch. Tank irrigation—by gravity flow and through lift irrigation with diesel pumps and rubber pipes—however was found to be common. Near Jambusar, where large tracts suffer from primary salinity, agriculture has been underdeveloped and careful application of surface irrigation can boost the economy. Unlike the command areas of Ukai-Kakrapar, Mahi and other canal systems, where the *Patidaar* cast population dominates the farming population, in the 40 villages we visited, the *Kshatriya* cast dominates the farming, and these are not as well known as Patidaars for their agrarian entrepreneurship. While we found stray cases of Saurashtra Patel cast population having acquired land and settled in the command area, there seemed no evidence of large-scale “strategic” land acquisition by enterprising farmers from outside the command as yet. In general, we found Kshatriya *(Jadejas, Darbars,* etc.), *Parmars and Prajapati* cast populations and a spattering of Harijans and tribals in most of the villages. Some of the villages in the Bharuch District have mixed Hindu and Muslim populations. Compared to the Mahi command area in the Kheda District, for instance, the villages we visited were agriculturally far more backward; and onset of irrigation will no doubt perk up the rural economy of this region in 3-5 years. Our surmise was that each of the 80,000 ha would produce at least Rs 8-10,000 in incremental value-added, thanks to Narmada irrigation (direct irrigation plus more productive well irrigation); and the cost of Narmada irrigation will be less than 10% of this increased value-added from farmland.

All the villages visited had taken some action to form WUAs under prompting from SSP field staff. However, almost everywhere, what we found were only Management Committees (MCs) with a president-designate. A few MCs had already had a general body meeting but none had actually begun enrolling irrigators as formal members of WUAs. A subsequent IWMI-Tata study (Talati and Liebrand 2003) showed that less than 3% of the farmers benefiting from Narmada water had paid their WUA membership fees. The study which surveyed farmers in 12 villages of the SSP command also found that while most farmers know the MC members, 62.5% did not know “the purpose of forming a WUA;” 50% did not know “about the meeting in which a WUA was formed;” 82% know nothing about the bylaws of the WUA and none know about the rules and regulations of the WUA. Expectedly, no WUA performed any of the three essential tasks they are expected to perform: indenting collation and water allocation, orderly distribution of water and collection of water charges.

The SSP's pricing and other policies too have been evolving only recently; and these had not been fully communicated to all the MCs as yet. There was also some confusion amongst MCs about the bylaws and specific clauses contained in them. Within the SSP staff too, there was a lack of clarity about how the report of the Government of Gujarat's Taskforce on PIM would affect the SSP WUAs. All in all, at the time of our fieldwork, there were great confusion and ambiguity about the design of WUAs, the bylaws, specific role of WUAs, and the pattern of interaction between irrigators and WUAs and between WUAs and the SSP. Later field studies suggest there has not been any major improvement in this condition since then.

We had expected to find some work initiated at the village level on creating the water distribution system below the minor by irrigation communities. However, in none of the 40 villages was there any move in this direction. On the contrary, we found significant resistance to the idea; in many villages, MC members categorically told us that sub-minors and field channels will never get built unless the government does it. There was some ambiguity about what the government/SSP will do to help; engineers accompanying us had told MCs that the government had recently taken the decision to acquire land for building sub-minors. Some MCs felt this would be welcome. The general impression the field staff gave farmers was that sub-minors to the chak level must be lined; and farmers seemed daunted by the cost of lining.

In any case, from our interaction with 40 village communities, we understood it is very unlikely that irrigation communities will construct sub-minors and field channels in a hurry, if at all. Half-hearted statements and rumors that the government might after all take over the responsibility of building distribution systems within VSAs have further reduced the chances that irrigation communities would take any initiative in this direction (Thomas 2004).A detailed case study of social dynamics in two chaks of the SSP command suggested that farmers do engage in primitive forms of fragmented collective action in building watercourses within small portions of the chaks; but conflicts amongst subgroups hinder or frustrate such efforts. It also does not help when this informal fragmented private and collective action results in the design of watercourses which are very different from the standardized design evolved by the SSP planners who are therefore not sympathetic to such uncoordinated attempts by groups of irrigators trying to secure access to Narmada irrigation (Thomas 2004). But the SSP-designed distribution systems are unlikely to get implemented for a long time to come, if ever.

What seems far more likely is that tiny areas adjoining the minors will be flow-irrigated, but a lot more area will be irrigated by lifting water from canals through diesel pumps and rubber pipes. Even farmers who can irrigate by gravity flow often prefer lifting water and conveying it through rubber pipes to avoid conflict with upstream farmers and to better control the flow (Thomas 2004). This mode of irrigation from canals, drains and tanks is already quite popular in many parts. Almost every village we visited had 10-20 diesel pump renters who also provide up to 1,000-1,500 feet of rubber pipes. Conveying lifted water 1-1.5 km using rubber pipes is quite common in the area. Therefore, rather than investing money and labor in building field channels and sub-minors, farmers will very likely use lift irrigation on a large scale. In many villages we covered, we found that farmers were already preparing to invest in diesel pump sets and pipes. Once they see water in the minors, very likely 5-10,000 new diesel pumps and some 4-5 thousand km of flexible pipes will come into the command area. The going rental rate for 5-7.5 hp diesel pumps was Rs 50-60/hour; but with the growing density of pumps, these rates will fall. In any case, pump irrigation markets will show a huge presence in the 80,000 ha command.

This was confirmed by a study we carried out during November 2002-March 2003. The Talati-Liebrand survey (2003) of 543 irrigators in 12 villages of the SSP command during rabi 2002-03 showed that of the 1,150 ha irrigated with Narmada water in the 12 villages surveyed, 727 ha were irrigated by lifting water, and the remainder by gravity flow or using siphons. It also showed that for every rupee they paid to the SSP Nigam for water charges, irrigators spent Rs 2.25 on lifting it from minors. Pump irrigation markets were booming with farmers lifting and transporting water up to 2,500 feet. Farmers in 10 of the 12 villages surveyed invested in 40 diesel pump sets with 5 to 8 hp capacity and 14,024 meter delivery pipes of various makes and materials, such as rubber, HDPE, fertilizer bag and PVC, to operate on the newly catalyzed water markets. A pump dealer whose business was on the upbeat and interviewed by Talati and Liebrand said he had already sold 30 pump sets in rabi 2002-03 itself, and expected to sell 350 the following year.

Providing SSP's water allocation of 5,200 m^3/ha will require an average of 150-200 hours of pump irrigation. At 150 hours/ha, the total value of water lifted to irrigate 80,000 ha will be around Rs 600 million. In some villages, farmers did complain that compared to other government sources, SSP is proposing a higher water fee and that they intend to levy the same fee for lift irrigation while the normal government policy is to charge half-rate for lift irrigation from canals and tanks. But our overall impression was that farmers will easily accept the higher water fees proposed. The SSP official water rate at Rs 150/ha for five irrigation turns for 80,000 ha should be just Rs 600 million, around 10% of the value they place on water. Thus, the SSP water fees are just a small fraction of the actual value farmers place on that water, and should not be difficult to collect at all; this however does not mean that SSP will be able to collect its Rs 600 million/season easily.

Some aspects we found in our interactions with farming groups which may have serious implications for the way the situation will evolve have to do with farmers' perceptions of SSP as an organization:

(a) While farmers were elated with the real prospects of getting Narmada water, they were also angered by repeated promises from SSP about when water would be available which remained unkept; farmers we met understood the constraints the project faced but felt that what SSP and its field staff say cannot be relied upon.

(b) This was further complicated by the fact that different members of the field staff had given different messages to the irrigation communities; in one village, for instance, the staff accompanying us explained that WUAs would have to collect water fees from flow irrigators as well as lift irrigators at the same rate; in the same village, another group of SSP staff had told farmers the same morning that the government's problem was of maximizing the use of water; so farmers can pump at will without worrying about water charges; such conflicting messages from SSP staff resulted in the erosion of credibility of the organization amongst farmers; this could only be resolved by having a clear and aggressive communication strategy for SSP.

(c) Often in good faith and almost casually, SSP field staff had liberally made commitments to irrigation communities to fix their specific local problems; in some villages, farmers came with complaints that some of their lands were waterlogged; in one village, the community wanted the bed of the minor raised so they could use siphons; in several, they wanted the SSP Nigam to provide water to fill their tanks; in some villages, where the paddy crop was burning because of moisture stress, farmers wanted Narmada water released immediately to save the paddy crop. Field staff accompanying us agreed so solve all their problems or at least to look into them. However, irrigators as well as SSP staff were certain that most of these commitments would not be kept, often because it is very difficult, or even impossible, to solve each individual farmer's problem in such a large system. Yet, farmers will not forget these commitments and will use them as a stick to beat the SSP with.

(d) One idea that was deeply ingrained in the minds of farmers is that SSP's need to release water into the system is greater and stronger than farmers' need to use the water; allowing this impression to continue must further erode SSP's capability to establish an orderly institutional arrangement for irrigation.

(e) Similarly, farmers and MCs we met assigned no seriousness or urgency to SSP's insistence on the operating practices it intends to pursue; for example, most farmers did not believe that water indents will not be honored unless they are made through WUAs; that WUAs which do not make an indent will not get water; that WUAs which do not pay their dues will be refused water for the next irrigation; that lift irrigation will actually be charged at the same rate as flow irrigation. It seemed to us that farmers take the SSP and the government so lightly that they were totally nonchalant about SSP's new water policy, which they did believe would be vigorously implemented.

Assessment

Overall, based on a brief stint of fieldwork during 2003 and follow-up studies later, our assessment is that it is unlikely the overall vision of the SSP for irrigation management will be played out for several seasons to come. Farmers are certainly not ready; but we think that even the SSP is not quite ready to implement its strategy. For example, even now, neither farmers nor field staff know where to obtain forms for indenting water. Field staff have not thought about what course of action is to be adopted in villages which have minors but which have not submitted their water indents, or if farmers begin to lift water en masse without submitting the indent.

It is unlikely that even in the long run, irrigation communities and WUAs will build below-the-minor distribution systems of the kind the SSP expects them to build.[1] Most villages will prefer instead to use lift irrigation and rubber pipes to distribute water. This means that there will be no planned, orderly water distribution by the WUAs. Instead, pump irrigation markets will proliferate. From the viewpoint of both water use efficiency and economical use

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[1] In building distribution systems within Village Service Areas, one problem farmers face is of high capital cost of pucca sub-minors; but the other is of acquiring land for sub-minors, which they feel only the government can do. There is some thinking in the government now about Sardar-Sarovar Narmada Nigam Limited acquiring the land for sub-minors and farmers contributing funds to build the distribution system. However, there is no clarity on the issue; in the meanwhile, lift irrigation from SSP canals has been going apace

of water, this arrangement would in some ways be even superior to the sub-minors and field channels envisaged by the SSP. Pipes will minimize seepage; and farmers paying Rs 50-60/hour for lift irrigation will strive to minimize wasteful use of water. Therefore, in our judgment, a distribution system based on private pump irrigation markets may not be necessarily bad and may even result in better use of the 21-inch irrigation requirement under SSP plans of provision.

Two bothersome issues about this are the use of energy and equitable distribution of water. Pump-irrigation-based distribution will mean avoidable use of 150-200 liters of fuel/ha; and it will be useful to examine if improved water use efficiency justifies this substantial incremental cost. A detailed and proper analysis of private, community and social-cost benefit issues involved in choosing between lift-based and gravity-based distribution systems is strongly indicated. The key gain from the former is that it will not require setting aside farmland for sub-minors and field channels which may cost Rs 0.4-0.5 million per minor, especially if land is acquired after irrigation arrives as will be the case in these parts of the Narmada command. The SSP has already been estimating the cost of a fairly good distribution system at around Rs 1-1.2 million/village, and a good part of it will require regular, annual maintenance. Contrast this with 50 7.5 hp pumps and 50 km of flexi pipes with a total capital investment of around Rs 1-1.25 million to distribute water over 500 ha. The annual fuel cost at 150 liters/ha would be Rs 1.5 million. So in opting for lift-based pump irrigation markets over constructing a gravity-flow distribution system, a village irrigation community is paying around Rs 1.5 million/year (plus the annual wear and tear, and replacement costs of pumps and pipes) to save two costs: (a) farmland, labor and other material needed to build channels and (b) transaction cost of organizing to build a common-property distribution system.

Gravity irrigation systems have their own equity issues between head- and tail-reach farmers. In a lift-irrigation-based water distribution system that may soon dominate the SSP command, equity issues will take a different spin in which topography will play an important part. Depending on the location of their farms in relation to the minor, and the topography of the area, different farmers will have differential access to canal irrigation. Lands adjoining the minor will get plentiful gravity flow; their owners will be the most privileged class.[2] Owners of lands who can get canal water by using siphons too will be privileged because they will not have to spend on lifting. Owners of fields further away and/or higher than the minor will be forced to lift; and those who are too resource-poor to own their own pumps and pipes will spend the most for irrigation. Since the lift involved is low, perhaps, it would be useful to promote low-lift diesel-operated and even manual and bullock-operated pumps for water distribution.

What might be the role of WUAs and PIM in the Narmada context, if distribution of water below the minor will be done by private lift irrigation suppliers? In our view, it would be considerably more limited than would be the case under gravity flow distribution. Indeed, the principal role the WUA would now be expected to play is collecting water fees from irrigators and indenting water on behalf of them from the SSP.

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[2] However, a deeper probe suggests that lowlands near minors may also face the problem of unwanted leakages, flooding and waterlogging, and their owners may not always and necessarily be better-off compared to owners of distant lands and uplands that require lift irrigation (Thomas 2004).

Immediate Priorities

In the immediate future, SSP can do little either to strengthen WUAs by capacity-building work or to encourage irrigation communities to build distribution infrastructure since there is no time to do either. In the medium to the long run, however, it should keep making efforts to do both. What it can do now, however, is important and can profoundly affect the way the project's O&M evolve over the coming years. Some of these are listed below:

1. *Indents for irrigation water:* The best and quickest way of energizing WUAs into functional bodies is for the SSP to ensure water indents are accepted only through WUAs; and that no farmer who has not submitted an indent through a WUA is allowed to use irrigation from the minor, either by gravity or by lift. In order that this happens, prior to each irrigation season, SSP needs to move fast, make indent forms available to WUA MCs and get them to complete these forms and submit them in a campaign mode.
2. *Advance collection of water fees:* This can be another measure that will energize WUAs. Although a widely used practice in Gujarat and elsewhere is to collect irrigation fees after irrigation is over, we believe that is the prime reason behind the low collection ratio. The SSP's current policy offers WUAs a 10% discount for advance payment. However, in our view, this gives irrigation communities scope to avoid having to organize now; MCs will take a pro-active attitude because they can wait until after the season is over to approach members for dues. This opportunity should not be given. Instead, the SSP should ask all those WUAs which want irrigation water to pay their water fees in advance. Doing this will mean that MCs will have to call the general body meeting, and will have to ask irrigators to pay up the water fees, which is the first step to catalyzing effective WUAs.
3. *Announce an irrigation schedule and adhere to it strictly and at all cost:* At present there is so much uncertainty and fluidity in the thinking of farmers as well as SSP field staff that nobody can say for sure when the first irrigation will be released, and how water will move around the system. In this situation, WUAs would find it difficult to even complete their indents. The SSP should finalize an irrigation schedule as soon as possible and widely disseminate it. It should clearly state which minors will be run at full supply during which weeks, the total number of weeks when water would be provided and so on so that farmers can plan their cropping patterns and schedules. Once these schedules are announced, they should be adhered to strictly. Doing this will enable MCs to call general body meetings and start collecting water fees in advance.
4. *Establish rules of the game:* The key task to be performed at this stage is to establish the rules of the game by which SSP will operate. Farmers now see SSP as a government body that would look after everything. SSP needs to break out of this mould and establish a fair *business* relationship with the users. This requires that its organization treats farmers as customers, like all good businesses and utilities do; at the same time, it needs to ensure that basic rules of the game of the business are adhered to by both parties. So SSP should provide a specified quantity of water along a specified schedule to irrigation communities which have indented water and paid for it in advance; but those communities that have not indented or not paid must be prevented from using Narmada water, no matter what. If this rule is not enforced in the first year, chances are that it will never be.

5. *Mechanisms for rule enforcement:* This is easier said than done. If minors in a certain distributary are running at full capacity for 7 days, how do WUAs catch defaulting farmers who lift water? How does SSP field staff ensure that WUAs which have not filed their indent or paid their advance do not encourage their farmers to lift water straight from the distributary or breach a nearby minor? Enforcing these rules of the game will be the biggest challenge for SSP. Catching all cases of unauthorized use will be impossible; but a functional level of rule compliance can, and must, be achieved. If SSP meets this challenge well in the first years by catching a significant proportion of cases of unauthorized irrigation and meting out exemplary penalty, rule-violation will decline in the future; but if numerous cases of unauthorized irrigation remain undetected and unchecked, anarchy will prevail, and it will become progressively more difficult to check it in the future.

Institutional Alternatives

The chaos currently prevailing in the SSP command is symptomatic of most canal irrigation projects in India. Although researchers still hark back to the philosophy of Command Area Development programs (Upadhyaya 2004) it is by now evident that these have done little to improve and sustain the performance of surface irrigation projects. Recent studies of major, medium and minor irrigation projects in six Indian states brought into bold relief how irrigation commands of all surface irrigation systems are shrinking (Joy and Paranjape 2003; Meher 2003; Rajagopal 2003; Shah 2003; Patil and Doraiswamy 2003; Vashishtha et al. 2003). These underscore the fact that while we have learnt to design and build irrigation systems, we have a long way to go in managing them for achieving their full potential for sustainable performance. Canal irrigation in India is at crossroads; and as a new large project, SSP can offer institutional answers with implications far beyond its own command area.

A default option for SSP is to *tighten the administration* within its existing operating framework by gearing up the SSP and government machinery to ensure tight rule enforcement. But the logistics of doing this presents a frightening prospect. It would imply intensive, round the clock campaigns to monitor water use at all levels of the system. Based on our assessment of how far the Sardar-Sarovar Narmada Nigam Limited is willing to go—and how long it can sustain that way—rule enforcement in this situation requires a level of effort that is unlikely in the governmental mode on a sustainable basis.

An alternative is to explore the Chinese approach to energize its local bureaucracy by restructuring its incentives. Facing much the same problems as Indian irrigation management has faced, the Chinese have responded differently (Shah et al. 2004). As in SSP, in many Chinese irrigation systems, while the state built the main canals and branches, village collectives were required to build the local distribution system. As in the SSP command, most village collectives did not build their distribution systems. As a result, many canal systems release water into a medium-sized reservoir from where water is conveyed by canals into ditches from which irrigators lift water. Besides the lifting costs, farmers have to pay for water too, as is envisaged in the SSP. But collecting water fee is difficult there as it is here; and so is enforcing the rule that user pays, and nonpayer does not use water. We found that in China's volumetric pricing system, constant measurement is not done, yet some benefits from volumetric charge are reaped. The engineer in charge of a reservoir with, say, 25 million m^3 of water capable of serving an irrigation area of, say, 8,000 ha is given an incentive on the performance of his fee collection. In small systems we saw in Hebei and Hanan provinces in North China, a standard loss allowance at 25% was provided to cover seepage and conveyance losses. So the incentive available to the official—over and above his salary—is 10% of the excess of total water fee collected less the base value of 75% of the dynamic storage in the reservoir costed at government-fixed water rate per m^3. Rough calculations showed that the total incentive earned is no more than 30-35% of the regular pay; yet, it generates accountability and efficiency we normally do not find in bureaucratic systems. There is growing evidence that this system has been working quite well in China.

Another alternative is to institute private franchises. Dr. Y. K. Alagh, Former Minister of Power, Science, Technology and Planning, India, has for long talked about a corporation for each of the Narmada branches. But a simpler idea is to invite private local entrepreneurs—as concessionaires or franchise holders—to bid for water transmission and fee collection from WUAs. If this is to work well, franchise operators will need to have medium- to long-term stakes; however, contracts can be suitably designed to protect the interests of the SSP, franchise holders as well as farmers.

In our view, what is critical at this stage of SSP is not the total amount of revenue the project generates or collects, or the total area it covers but to firmly establish the basic rules of the game which in our opinion should number five: (a) SSP will provide assured irrigation in specified quantities at preannounced schedules; (b) it will receive indents for irrigation only from WUAs and not from individual members; (c) it will not supply water to any WUA unless it has deposited the water fee in advance; (d) once the irrigation starts, nobody who has not indented or paid for water will be permitted to use water, no matter what; and (e) SSP or its staff will not make commitments to farmers that it cannot keep, and if commitments are made, they should be kept at any cost. If these basic rules of the game are not established now, the SSP will most likely go the way other irrigation projects have.

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Groundwater Externalities of Large Surface Irrigation Transfers:

Lessons from *Indira Gandhi Nahar Pariyojana,* Rajasthan, India

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Introduction

Indira Gandhi Nahar Pariyojana (IGNP) was among the first group of large surface water transfer projects taken up in the country aiming to transform the wastelands of Thar Desert in Rajasthan into agriculturally productive zones along with improvement of afforestation and environment, development and protection of livestock/animal health, human rehabilitation and settlement, and economic growth of the poor people of the desert. The project had laudable objectives of "drought proofing, provision of drinking water, industrial and irrigation facilities, creation of employment opportunities, settlement of human population of thinly populated desert areasi; improvement of fodder, forage and agriculture facilities, check spread of desert area and improve ecosystem through large-scale afforestation, develop road network and provide requisite opportunities for overall economic development" (IGNB 2002). Over the years, some of these objectives have been adequately met. At the same time, this large transfer of surface water from alluvial plains to a desert region with no natural drainage and over 250 km away leads to a massive spread of waterlogging and salinity, inundation of vast land depressions and adjoining habitations, roads and public property and fast spread of water-induced animal and human diseases. IGNP presents a great lesson to water infrastructural planners and managers on how inadequacies in planning and operation of large surface irrigation transfers can create negative groundwater externalities of unforeseen magnitude which fail to be tackled by normal quickfix solutions. This paper, a part of the Strategic Analyses of the National River Linking Project, attempts to diagnose and analyze this problem, and drawing lessons from the past failed-interventions offers a certain viable strategy for IGNP and other large future projects of surface water transfers elsewhere.

IGNP-The Project

IGNP is a large water infrastructural project designed for transferring 9.36 Bm^3 (7.59 milion acre feet) of Rajasthan's share agreed under the Indus Water Treaty (1960)/and Inter-State Water Agreement (1981). The water from the Harike Barrage in Punjab is transferred to the western desert region of Rajasthan through a 200 km long feeder canal. The system is designed to irrigate 2.5 Mha of Thar Desert through an extensive network of a more than 9,000 km length of distribution system and 450 km length of main canals. Irrgation in IGNP is developed in stages popularly known as Stage-I and Stage-II. The IGNP Stage-I consists of a head feeder reach of 204 km offtaking from the Harike Barrage, a 189 km main canal and a 3,454 km long distribution system with a culturable command area (CCA) of 541,000 ha. The IGNP Stage-II, commencing with a 189 km main canal, consists of the lower reaches of the project comprising a 256 km long main canal and a 5,606 km long distribution system with a CCA of 1,319,000 ha.

The canal network is lined and able to bring large quantities of water to irrigate an extensive area of what was a low-value desert. Land brought into the scheme is allotted to persons applying for land, with a carefully developed system of prioritization of applications to identify the most deserving applicants. Each allotment is 25 *bighas* (6.32 ha) in area. The applicants with the highest priority are from the region being developed; nevertheless, there have been extensive population shifts into the project area to take advantage of the potential created. Stage-I started receiving irrigation since October 1961 and Stage-II is still under construction.

By 2004-05, 559,000 ha irrigation potential was created under Stage I and 510,000 ha under Stage II. Irrigation potential is deemed to be created only when watercourses are constructed, and water is provided through outlets for a *murabba* of 6.32 ha. Irrigation potential created and utilized for some selected years for Stage-I and Stage-II of IGNP is given in Table 1. The development activities of the command area for the IGNP command, which included, among others, the construction of lined watercourses to the outlets, land leveling and shaping and soil conservation, started in 1974.

Table 1. Progressive development of irrigation potential created and utilized under Stage-I and Stage-II of IGNP.

Year	Stage-I					Stage-II				
	Through canal		Through watercourse		Utilized	Through canal		Through watercourse		Utilized
	Area opend (lakh ha)	Potential created (with 110% irrigation intensity)	Area covered (lakh ha)	Irrigation potential created (110%)		Area opend (lakh ha)	Potential created (with 110% irrigation intensity)	Area covered (lakh ha)	Irrigation potential created (110%)	
74-75	2.86	3.15	0	0	2.58	-	-	-	-	-
81-82	4.86	5.35	2.07	2.28	4.02	0.35	0.28	0	0	0
88-89	5.22	5.74	4.08	4.49	5.53	1.45	1.16	0.3	0.24	0.12
95-96	5.31	5.84	4.42	4.86	6.64	5.09	4.07	2.85	2.28	1.37
2000-01	5.42	5.96	4.69	5.16	6.28	7.55	6.04	5.13	4.1	2.08
2004-05	5.46	6.01	5.08	5.59	6.88	9.26	7.41	6.37	5.1	1.44

However, the data clearly indicate a substantial lag period between the release of water through the canals, completion of the watercourses for conveyance of water to the fields and actual utilization of the water. The large amounts of unused water became a major source of inundation of the depressions and subsequent waterlogging.

Irrigation and Agricultural Transformation

Before the advent of IGNP there was very little irrgated area in Jaisalmer (0.54%) and Bikaner (7%) districts which have now increased substantially in all the four districts (Table 2) under the command. Most of the irrigated area in all the four districts in 2001-02 is from canal irrigation. As a result of irrigation, the net sown area in Bikaner and Jaisalmer districts increased gradually, whereas there is not much change in Sri Ganaganagar and Hanumangarh districts.

Table 2. District-wise irrigated area as a percent of net sown area in the IGNP command.

Year	Sri Ganganagar	Hanumangarh	Bikaner	Jaisalmer
1988-89	70.54	*	7.04	0.54
1996-97	43.31	38.69	10.23	8.47
2000-2001	81.73	49.39	18.38	20.86
2001-2002**	75.05	40.05	17.94	22.33

*Until 1992/93, ster the Hanumangarh District was part of the Sri Ganganagar District.

**2002 was a drought year in the region.

In 1974-75, the cropping pattern generally followed by the farmers was cotton, pearl millet, *kharif* (monsoon from May to september) pulses and *guar* (cluster bean) in the kharif season and wheat, barley, gram and mustard in the *rabi* (October to April) season. However, with the introduction of irrigation under IGNP, the area covered under cotton, wheat and mustard, and their productivity has increased over the years. The data indicate that the total coverage under kharif and rabi crops during 1974-75 under Stage I was only 258,178 ha, which increased to 653,948 ha in 2000-01, an increase of about 250%. In Stage II, the area under kharif and rabi crops in 2001-02 was 152,859 ha. The area decreased in 2002-03 due to scanty rainfall and less water availability in the canal, but picked up in the subsequent years. The areas under cotton and groundnut have increased whereas the area under pearl millet has decreased (Table 3). In the rabi season the area under wheat, mustard and fodder increased. Yields of cotton and wheat have more than doubled in Stage I (Table 4) and in Stage II the crop yields are still low. Overall, except for the wheat crop, the yield gains have not been very impressive perhaps due to widespread prevalence of waterlogging and salinity and very limited use of groundwater. Studies made in neighboring Punjab showed that areas purely under canal irrigation had lower wheat yields than those with conjunctive and pure tube well irrigation.

Table 3. Area under different crops in Stage-I of the IGNP command.

Crops	1974-75		1990-91		1995-96		2000-01*	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Cotton	23,090	24.9	153,809	63.3	206,282	70.3	180,626	54.6
Pearl millet	14,435	15.8	2,148	0.9	3,047	1.1	2,003	0.6
Paddy	6,655	7.2	6,926	2.8	8,563	3.0	18,426	5.6
Wheat	49,973	30.2	133,392	44.5	179,396	45.5	158,956	49.2
Gram	66,733	40.3	59,798	19.9	61,058	15.5	42,117	13.0
Mustard	32,941	19.9	83,741	27.9	95,815	24.3	59,419	18.4
Barley	9,859	5.9	4,642	1.6	7,265	1.8	21,486	6.7

*Low rainfall year.

Table 4. Changes in yield of various crops under the IGNP command.

Years	Cotton	Groundnut	Guar	Wheat	Gram	Mustard
STAGE- I	8.91	-	-	12.71	7.36	6.22
74-75	10.41	16.00	-	18.25	8.20	6.20
80-81	16.72	14.21	9.21	27.72	5.53	10.84
90-91	13.15	10.80	7.52	29.64	7.54	10.11
99-2000	11.50	13.00	6.50	13.00	8.00	7.00
2000-01*						
STAGE- II	8.83	15.70	4.32	17.13	10.81	8.82
95-96	10.50	13.00	6.00	15.00	9.00	8.00
2000-01	8.50	11.50	2.50	20.00	10.00	10.00
2004-05						

* Low rainfall year.

Groundwater: The Resource and the Threat

Most of the command area of IGNP-Stage I has an alluvial cover of more than 20 m and can be a potential source of groundwater depending on the aquifer characteristics and the quality of recharged water. The tube wells of 250 m depth in unconsolidated formations, covering 95% of the investigated area, are capable of yielding 12 to 120 m^3/hr for a drawdown from 4 to 15 m. However, the drilling data of Central Groundwater Board (CGWB 1999) and Rajasthan Groundwater Department have exhibited considerable lateral and vertical variations in lithology in the IGNP Stage-I area. In the northeast to southwest directions three main aquifers between the depth ranges of 15-50 m, 45-100 m and 80-170 meters below ground level (m bgl) have been revealed in the investigations down to a depth of 210 m bgl.

The formations in Stage-II comprise mainly quaternary (47% of CCA) and tertiary (47% of CCA) formations. The formation of Jaisalmer and Barmer districts contains water that is highly mineralized, but at many places usable for small livestock. The most worrying feature is that beneath the sandy surface soil shale/clay, hard compact friable carbonate nodules and lime-coated gravel with clay are present at varying depths having a poor infiltration rate and behaving as an impervious barrier. In about 30 to 35% of the area under Stage II, the depth up to these hydrological barriers is less than 10 m bgl, being shallower in lift areas and becoming deeper towards the international boundary (CAD 1997, 1999). Based on available data, distribution of area having a hard pan layer within 0 to 10 m bgl in different *tehsils* is given in Table 5.It appears that about 33.4% in flow command and 76.4% in lift command (excluding the Sahwa lift area) are prone to waterlogging due to the presence of the hardpan layer. Due to lack of detailed investigations before the development of the irrigation commands, this particular feature of hydrogeology perhaps did not receive adequate attention during the irrigation planning and operations phase and was one of the major reason for the catastrophic spread of waterlogging and salinity in the IGNP command areas.

The deeper groundwater is mostly saline and about 530,500 ha (or 47% of the total area) have groundwater salinities of more than 8 dS/m. About 145,000 ha (or 13% of the area) have groundwater salinity less than 2 dS/m. Deeper native saline groundwater is often overlain by better-quality groundwaters originating from percolation and seepage in the canal irrigated area. Overall, there is very little groundwater irrigation in all the four districts (DoES 1988, 1995, 1996, 2004). But in the recent years the area under tube well irrigation has been increasing. This may be due to the reduced canal supplies and low rainfall.

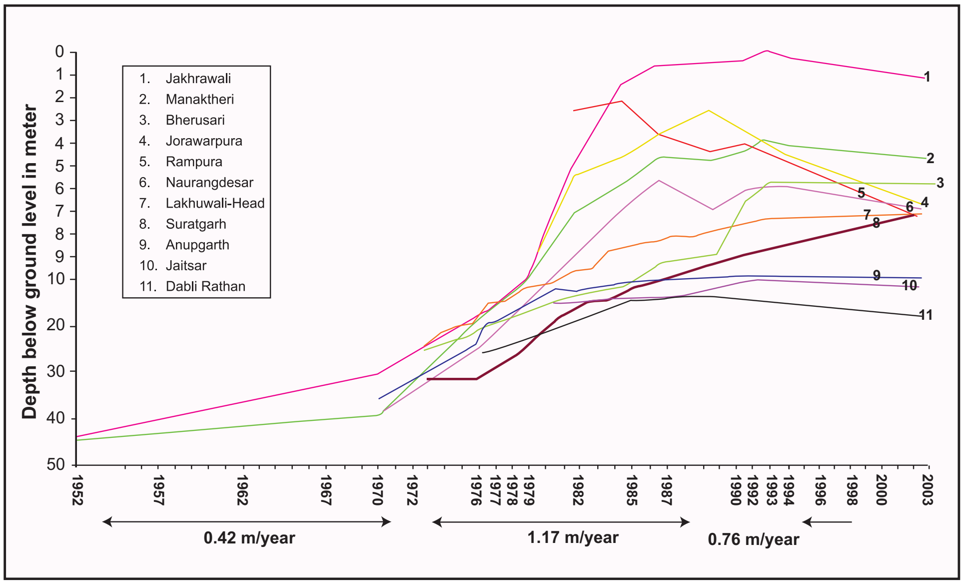
Table 5. Distribution of area with hardpan 0 to 10 m from ground level - IGNP Stage II.

System	Tehsil	CCA, ha	Hardpan area	
			ha	%
Flow area				
Dattor distributary	Pugal	18,820	13,770	73.2
Birsalpur branch	Kolayat	44,970	9,110	20.3
Charanwali branch	Kolayat, Nachana	102,240	16,390	16.0
Shahid Birbal branch	Mohangarh	101,160	31,580	31.2
Sagar Mal Gopa branch	Ramgarh, Jaisalmer	255,450	92,300	36.1
Other direct outlets, etc.		98,730	44,740	45.3
Subtotal		621,370	207,890	33.4
Lift area				
Gajner lift	Bikaner, Kolayat	49,540	21,600	43.6
Kolayat lift	Kolayat, Phalodi	86,260	63,470	73.6
Phalodi lift	Phalodi, Pokaran	56,750	56,750	100.0
Pokaran lift	Pokaran	22,700	22,700	100.0
Subtotal		215,250	164,520	76.4
Grand total		836,620	372,410	44.5

Spread of Waterlogging and Soil Salinity

Rise of Water Levels: With the expansion of area under irrigation, the command area witnessed an alarming expansion of waterlogging and soil salinity. Before the advent of irrigation in 1952, the groundwater table was at a depth of about 40 to 50 m. With the commissioning of IGNP and flow of canals and return flows for the period, an average rise of groundwater of 0.42 m/annum was observed for the two-decade period of 1952-72 (Figure 1).

Figure 1. Hydrograph showing grounderwater depth chages (Year 1952 to 2003).



An abrupt rise in water levels was also recorded in Lakhuwali, Naurangdesar, Rampura, Jorawarpura, Bherusari, Manaktheri and Jakharawali. The maximum and minimum rise of water levels was observed as 1.30 and 0.6 m per year in the areas of Suratgarh and Dabli Kalan, respectfully, during the period 1973-93.

During a decadal period of 1972-88, there was a substantial rise in water levels up to 1.17 m per year, which could be attributed to return flow of irrigation, high water allowances of 5 m^3/sec./1,000 acres, excess irrigation applications (Table 6) and filling up of depressions. By 1994/95, the rate of rise was found to be 0.80 m in Stage I and 0.33 m in

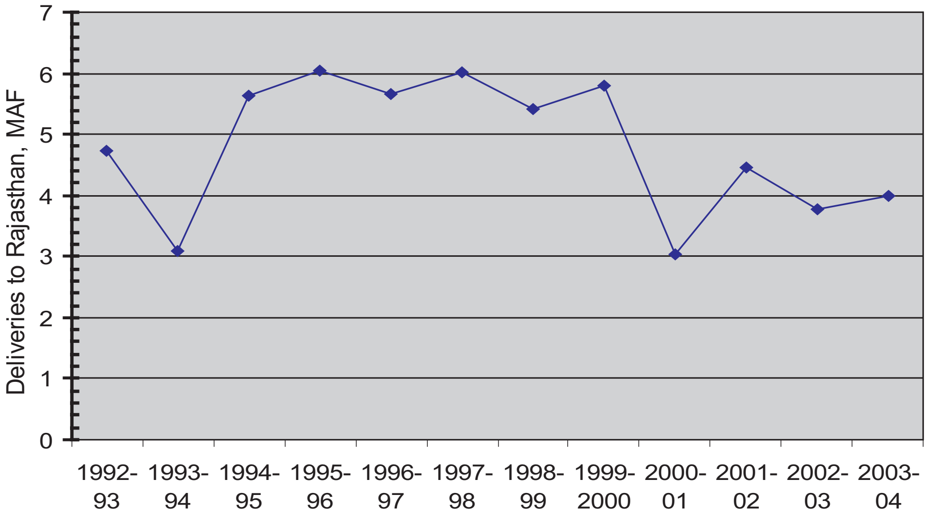
Stage II. Fortunately, after 2000 a declining trend of groundwater depths is noticed, attributed to less than normal rainfall and poor availability of water supply in canals. Even during normal years, supplies to Rajasthan have been lesser than the agreed quota, but recent years have witnessed a marked reduction (Figure 2). This was also aided by some additional groundwater development by the farmers in Hanumangarh and Bikaner districts under Stage-I and to a lesser extent in Stage-II.

Table 6. Depth of seasonal water requirement and deliveries (in cm of water) in selected reaches of IGNP.

System		Kharif			Rabi		
		1984	1985	1986	1984	1985	1986
Surathgarh branch Controlled area	Irrigation requirement	71.0	53.9	59.1	65.8	52.4	52.1
	Actual supplies	140.8	102.7	114.8	55.5	114.9	69.8
Anupgarh branch Controlled area	Irrigation requirement	66.8	51.5	59.4	52.7	53.3	52.7
	Actual supplies	125.2	96.0	108.0	53.6	86.3	63.4
Rawatsar distributary IWMZ*	Irrigation requirement	68.0	51.5	61.3	53.9	53.9	53.0
	Actual supplies	97.2	60.4	76.2	57.0	68.0	59.1
Naurangdesar distributary IWMZ*	Irrigation requirement	70.1	60.0	68.3	54.3	54.6	53.3
	Actual supplies	61.6	48.2	51.5	46.0	46.6	44.8

* Improved water management pilot project initiated in 1981 in about 4,000 ha and expanded to about 89,098 ha by 1991 in Phase I of Stage I (IGNB 2002).

Figure 2. Actual water supplies to IGNP.



Spread of Waterlogging: Rise in groundwater levels afflicted large areas with waterlogging and critical water table conditions. The extent of such areas increased continuously up to the year 1997-98 and has shown some respite only in recent years (Table 7). During 1997-98, an area of 23,251 ha was affected with severe waterlogging. The causes of such a spread were both natural and man-made. This region has no natural drainage system and the water transferred is either lost through evaporation (and transpiration) or is stored in the groundwater system. Wherever the groundwater system is exposed to the topographically low areas, pools of surface water are formed. Additionally, about 30% of the area in Stage I and about 45% of the area in Stage II have hydrological barriers in the form of gypsum, clay and kankar layers which appear in the shallow region of less than 10 m in most of the area causing buildup of perched water tables.

Table 7. Development of waterlogging (area in ha) in the IGNP command.

Category	1992-93	1997-98	2000-01	2003-04
Potentially sensitive area (water table within 1.5 to 6.0 m)	202,960	328,123	237,337	195,000
Critical area (water table within 1.0 to 1.5 m)	22,000	32,552	15,654	9,576
Waterlogged area (water table within 0.0 to 1.0 m)	13,750	23,251	13,041	2,535
All categories	238,710	383,926	266,032	207,111

Besides the natural causes, several management and operational practices have also exacerbated the situation:

i. Ghaggar river floodwater stored in depressions contributed substantially to groundwater recharge in the neighboring areas.

ii. Several inter-dunal low-lying areas filled up with canal water to meet requirements during construction remained unused.

iii. Very high water allowance of 5.23 cusec/1,000 acres in Stage I caused high seepage losses from unlined watercorses/field channels and return flows.

iv. Uncontrolled high discharge direct outlets from the main canal and branches caused flooding of large areas.

v. Absence of gates and controls on minors and watercourses caused flooding of low areas during low/no irrigation requirements.

Impact of Waterlogging

Rise of the water table closer to the surface and inundation of the low-lying areas have caused submegence of agricultural lands and village common lands, submergence of the villages/ habitations, damages to road communication and public utilities and constraints in the choice of crops and loss of production. The damages have taken place extensively in several areas and about 4,000 ha of agriculture, village common lands and government lands have been partly or completely submerged resulting in complete loss of the assets. Waterlogging conditions have resulted in the submergence of 22 villages due to exposure of the hydrostatic line of the groundwater and leakages and return flows from the irrigation system. The main pockets of submerged lands are shown in Table 8. Several of the marooned villages (Rangmahal, Samnala Quarter, Manaktheri, Baropal, Jakharawali, Bherusari, Rawatsar, Dabli Kalan, Dabli Khurd, Lunio ki Dhani, Ghandheli, 13/15 SPD, Kalalon ki Dhani, Jowrapura, etc.) had to be shifted to higher elevations at huge public costs and distress. Large sections of the road systems also got submeged and required repeated raising of road levels. Several schools, hospitals, and other public service utilities also got submeged affecting the society as a whole.

Table 8. Pockets of submerged lands in the IGNP command (ha).

1.	Manaktheri-Baropal-Jakharawali-Bherusari, Kalalon Wali Dhani	2,500
2.	Dabli Khurd and Dabli Kalan	500
3.	Lunio ki Dhani	55
4.	Masitawali head and head reaches of Naurangdesar	33
5.	Rawatsar, Gandheli, Dasuwali, 2,3 RWD, 34 RWD	650
6.	Nachana	50

Loss to Agricultural Production: By the end of year 1997-98, a total CCA of 514,000 ha in Stage I, which is around 56% of the total area, had become potentially sensitive to waterlogging (CAD, 2004, 2005, 2007b). In Stage II, out of 182,000 ha utilized for irrigation about 23,000 ha (about 13%) had become potentially sensitive to waterlogging. Some waterlogged areas have completely gone out of cultivation, where the water table is either above the ground surface or very close to the surface. Waterlogged areas have also gone out of cultivation due to salinization. Waterlogging seriously constrains the choice of crops, enhances expenditure on farm operations and strongly affects the growth and yield of crops.

To have a better understanding of the existing cropping patterns, sources of irrigation, yield levels and net returns of the farmers in the command, a survey of 253 farmers (184 farmers in Stage I and 69 farmers in Stage II) cultivating an area of 1,241 ha was undertaken during 2007. Salient findings from the farm survey were:

i. More than 50% of the irrigated area in Stage I had water tables within sensitive zones during the late nineties. About 10% of the soil surveyed in the command showed high salinity conditions. It is, therefore, necessary to safeguard the gains of IGNP in terms of increased cropped area and production, socioeconomic life of the settled farmers and public utilities from the vagaries of waterlogging and soil salinity. Primary data collected by IWMI (IWMI 2007) showed that 98% of farmers depend only on agriculture for family income and livelihoods. Most of the farmers are marginal to medium with an average cultivated area of 5.58 ha per farm family. Only about 14.6% are large farmers.

ii. Canal irrigation (96.4%) remains the major source of irrigation. However, in recent years farmers have shown good interest in tube well irrigation as 44% of the surveyed farmers also owned tube wells. In the early 1990s, the major source of irrigation in these districts was only canal water. The average depth of tube wells is about 38 m indicating that tube wells are shallow and mostly tapping freshwater lenses floating on parent saline water. The average pump set capacity is about 9.0 hp, cost of installation is about INR 51,000 and operation and maintenance (O&M) cost is high at INR 1189/ha as almost all the tube wells are diesel-operated.

iii. The cropping intensity in IGNP is 130% with 149% under Stage I and 110% under Stage II. About 31% in kharif and 30% in rabi have remained fallow mainly due to deficit canal supplies. In Stage I only about 20% remained fallow against 44% fallow lands in Stage II, mainly due to deficit water supplies for Stage II and more groundwater availability in Stage I. Cultivation in about 4.4% of the area has been abandoned due to waterlogging and salinity - about 5.7% area in Stage I and 2.4% in Stage II.

iv. Cotton occupied the largest area (55%) in the kharif season followed by cluster bean (29%) and oil seeds (7%) in Stage I. In the same season, water-deficit farmers in Stage II mainly cultivated cluster bean (64%), groundnut (17%) and cotton (8%). During rabi, wheat (64%) and mustard (26%) were the main crops under Stage I as compared to barley (37%), mustard (29%) and gram (24%) under Stage II. So the farmers in Stage II cultivate the crops having minimum water requirements during both seasons.

v. The average crop yields in the command were somewhat comparable to the average yields of the state with variations of 1.7 t/ha cotton in Hanumangarh and 0.7 t/ha in Lunkaransar. Similarly, wheat yields varied from 0.4 to 3.4 t/ha with an average yield of 2.3 t/ha in Stage I and 2.0 t/ha in Stage II. The data did not support a good impact of source of irrigation on crop yields.

vi. Waterlogging (28% of respondents) and soil salinity (26% of respondents) are major problems in IGNP with a lot of area submerged under pools of water, cultivation of some areas abandoned and other lands producing much less than crop potential yields. The farmers reported that, on average, the additional expenditure due to waterlogging and soil salinity on practices like field preparation, enhanced seed rate and fertilizer applications is to the tune of Rs 1,095/ha. With the problem of waterlogging and soil salinity, the average cotton crop yields are low at 13 quintal/ha (q/ha) compared to about 15 q/ha in normal soils under Stage I. The same is the case with cluster bean, wheat, mustard and gram. In fact, the reduction in gram yields due to waterlogging and soil salinity is about 50%.

vii. The cropping pattern of cotton and wheat gives an average net return of about INR 25,000/ha/year. The net return from the gram crop is about INR 8,000/ha. In the case of areas affected by waterlogging and soil salinity the net returns are lower by about 25% in the case of cotton and by 46% in the case of the wheat crop.

With about 56% of the command having some degree of waterlogging problems, the loss to agricultural economy, with the increased crop production expenses and reduced crop yields, is huge. The problem is also causing extensive social costs as a result of submerged villages and the road network and migration of farmers from affected areas to new areas.

Interventions Attempted

Several ameliorative interventions have been attempted on a pilot scale to mitigate waterlogging and salinity in the IGNP command. These interventions, mainly biophysical in nature, included reduction in water allowance and drainage pilots for surface drainage, subsurface drainge, tube well drainage, skimming wells and bio-drainage (CAD 2007a). Most of the interventions faced operational, managemental, finanacial and institutional challenges and could not be upscaled for wider adoption in the command.

i. The CAD-installed vertical drainage systems faced considerable problems in terms of infrastructural arrangements for operation, availability of electricity, and a shared institution and have been put under operation for a short period of 2 to 3 years with periodical interruptions in pump operations. Though the results indicated that, to some extent, groundwater levels can be controlled, these projects have been discontinued due to huge costs involved.

ii. Installation of the subsurface drainage shows its beneficial effects in reclaiming waterlogged saline soils in a short span of 2 to 3 years in several subsurface drainage projects in the country (HOPP 2001). The subsurface drainage projects installed in IGNP also showed similar improvements. However, the technology is new to the area. The pilot projects need to be operated and monitored for evaluating the impacts and the effects on society and environment including the options for disposal of drainage effluent, which is a major challenge. The costs involved are huge (Rs 30,000 to 40,000/ha) and can be implemented only inder a state-sponsored program.

iii. Attempts were also made to decongest the large surfce water pondages. The experince showed that pumping for dewatering the stagnated water bodies is not a one-time activity, but it has to be a perennial one. Further, the cost of pumping of water is also very high. It has been concluded that dewatering through pumping operations would not be an economically viable proposition. Moreover, it is very likely that the decrease in standing water levels achieved by pumping will be nullified with inflows during the seasonal rains and irrigation spills.

iv. Bio-drainage with eucalyptus species was also attempted along small stretches of the canals. The experiences were good only along certain patches where the plants survived but failed due to continuous water stagnation. The bio-plantations may be used in certain waterlogged wastelands with suitable species and management practices. It has very limited success for controlling waterlogging of the agricultural lands.

v. However, the farmers are taking up tube well irrigation increasingly (especially under Stage I) and the adverse impact of fluctuating canal supplies on cropping intensity could be mitigated to some extent by adopting large-scale conjunctive use. The spread is slow due to higher costs and nonavailability of electricity to run the tube wells. Diesel-operated medium/deep tube wells are less cost-effective.

Moreover, most of these scientific interventions were top-down with limited participation of the communities and setting up of effective institutions for asset ownership, O&M and cost and benefit sharing mechanisms. As such, these had limited acceptance and had to be abandoned after the initial enthusiasm for implementation subsided and ground realities were sincerely appreciated.

Strategy for Groundwater Management

Provision of canals, the distribution system and the application of surface water to such a large area, besides providing direct irrigation benefits, also assists in modification of the groundwater regime. Such groundwater externalities may be both positive in the form of additional recharge and improvements in the water table in a water-stressed area and negative through creation of waterlogging, water-quality problems and soil salinity in previously water-congested pockets. The planning for integrated use of canal and groundwater will mot likely alleviate some of these problems and improve water use efficiency and productivity. Attempts have been made earlier in planning conjunctive use of groundwater and canal supplies for Haryana (Tyagi 2006) and for Punjab (Sondhi and Kaushal 2006) using simulation modeling techniques. Some studies have also been made in IGNP for projecting the problems of waterlogging and soil salinity and evaluating various options for problem amelioration (ORG 1996, 1999; NIH 1996).

From the experiences of IGNP and experiences elsewhere, it is certain that there are no global solutions to problems of such unprecedented magnitude. It is proposed that according to the extent of the problem, the affected areas may be broadly divided into the following three categories and appropriate measures implemented both on short- and long-term bases.

i. *Converting water-ponded areas as wetlands*: As the IGNP command has no natural and man-made drainage, the inundated areas may be designated as wetlands and used as receiving bodies for the irrigation return flows and surface and subsurface drainage effluents. These wetlands can also be put for economic use like freshwater and saline water fisheries according to the water quality. The alternative plan of transferring such poor-quality water through a dedicated canal to the Arabian sea requires large investments and cooperation of the neighboring country.

ii. *Enhancing tube well development in waterlogged areas*: Areas afflicted with the waterlogging problem may be ameliorated, among others, through appropriate groundwater management practices. A large portion of the command has developed freshwater layers closer to the surface and below, and conjunctive use of canal water and groundwater in this area will result in controlling of the groundwater table. The installation and operation of tube wells by the government have not produced encouraging results. The increasing installation of private tube wells and successful use of groundwater for irrigation by the farmers in the last few canal supply deficit years have shown that the conjunctive use of canal water and groundwater is viable in the IGNP command. However, the results of the conjunctive use on the control of the water table will not be visible in a short time. Long-term planning is required in promoting conjunctive use of canal water and groundwater, which involves :

    a. Institutional support for delineating the aquifers suitable for tube well installation and identifying appropriate technologies for well construction to avoid rising of saline water.

    b. Canal supply management practices for providing reduced irrigation allowance on *warabandi* and subsidies and policy support.

    c. Priority in energization of the tube wells in the IGNP command can be one of the supports from the government that will encourage the farmers to opt for tube well irrigation.

iii. *Subsurface drainage for saline-waterlogged areas*: The areas with soil salinity associated with saline groundwater require subsurface drainage to leach out salts and maintain a favorable salt balance in the root zone. The pilot projects on subsurface drainage have shown that salinity in the root zones can be quickly reduced when the cropping intensity will increase and crop yield will be more than double. However, this technology requires the participation of a group of farmers having contiguous land parcels and also issues like disposal/reuse of drainage effluent need to be addressed before embarking on large-scale adoption. The already installed successful pilots on subsurface drainage (SSD) systems may be operated and monitored for deriving experience on these issues. Besides the technical operation of the infrastructure, establishing an effective drainage farmer group/association is crucial for its long-term sustainability.

Conclusions and Recommendations

Transfer of large amounts surface irrigation water through an elaborate water conveyance and distribution infrastructure under IGNP helped India to make use of its share of the Sutlej river water as established under the Indus Water Treaty. Availability of water in this dry area helped tremendously in the expansion in cropped/irrigated area and a substantial change in agricultural land productivity, improved socioeconomic conditions, and in the general well-being of the local poor and immigrant communities, and greening of the desert area. The advent of irrigation has resulted in rapid changes in the hydrologic regime and groundwater conditions. During the past about four decades, the groundwater levels have risen by more than 1.0 m per year and more than 50% of the command area now has groundwater levels in sensitive zones (> 6.0 m bgl). Substantial areas have gone out of cultivation due to water stagnation/inundation, waterlogging and soil salinity. A considerable loss to the agro-economy is being incurred due to constraints in the choice of crops, higher costs of cultivation and low crop yields caused by waterlogging and soil salinity. Several of the ad-hoc technical measures implemented in the form of pilot projects on the hot-spots have met with little success and acceptance by the farming communities and have been either abandoned or operated on a lower scale. The recent spurt in the development of private tube wells, especially under Stage I of IGNP, caused by deficit canal water supplies as a whole to the IGNP and also opening up of areas under Stage II of the command, have shown a positive impact through lowering of water tables and better crop yields.

The waterlogging and soil salinity areas of IGNP require interinstitutional cooperation and action plans with irrigation, groundwater, agriculture and other concerned departments, CAD and other research and development institutions, local NGOs and farmer bodies to develop and implement short- and long-term plans of groundwater management strategy and other innovative ideas. Among the strategies this paper suggests dividing the affected areas into three broad categories and introducing appropriate interventions. These include i) water-ponded areas—treat them as wetlands and use appropriate economic activities such as saline water fisheries, ii) waterlogged areas—enhance tubewell irrigation in waterlogged areas and provide policy and institutional support on technology, management of canal water supply and energy provision, and iii) saline groundwater affected areas—provide subsurface drainage for leaching out the salt and create a favorable soil-balance condition at the root zone.

The planning, development, implementation and operation of the large and long-distance surface irrigation water transfer and distribution infrastructure under the IGNP have provided several important lessons of enormous cost for all those involved in improving the welfare of people and ensuring food security through large-scale land- and water-centric interventions. Professionals with their defined areas of expertise will draw lessons so as to sharpen the future line of thinking and action. But one thing is certain, which is that all future water infrastructural plans elsewhere and especially those envisaged under the National River Linking Project of India must ensure that while achieving the highest positive impacts the present and future negative externalities must remain at a minimum.

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Managing Rehabilitation and Resettlement of the Involuntarily Involuntarily Displaced Population: Lessons from Selected Hydro Projects in India

Madar Samad, Zhankana Shah, Sridhar Acharyulu and Shreedhar Acharya[1]

Introduction

Despite the vast national and international experiences in, and the existence of several guidelines on, managing involuntarily displaced persons (IDPs), resettlement and rehabilitation (R&R) of displaced populations continue to be a difficult problem. Involuntary displacement not only puts the affected people at serious risk of impoverishment but also reverses the entire poverty reduction efforts. The establishment of dams for irrigation and hydropower are often associated with large-scale displacement of rural communities.[2] In India in particular, public controversies and civil society concerns about IDPs are intenser than in many other developing countries. This is understandable. India is the third largest dam-building country in the world with some 4,290 dams and, possibly, it has the largest number of development-induced IDPs in the world.[3] There are no authentic statistics about the number of IDPs. Estimates based on the number of dams constructed since Independence indicate that as many as 21 to 33 million persons are likely to have been displaced (Fernandes 2000: 277; Mander et al. 1999: 5) These estimates do not include persons displaced by canals, or by the construction of colonies or other infrastructure. Neither do they include those who have been subjected to multiple displacements (Rangachari 2000: 116-117).[4] According to Human Rights Watch, indigenous peoples, known as *Adivasis* or Scheduled Tribes suffer from high rates of displacement. They make up 8% of the total population but constitute 55% of IDPs (Human Rights Watch 2006). Statistics related to the National River Linking Project suggest that around 0.5 million people will be displaced due to peninsular links alone and millions in other river-link areas.

Empirical evidence accumulated over the years has shown that, in most cases, displacement has resulted in deprivations and severe impoverishments. In India, agitations by the civil organizations such the Narmada Bachao Andolan (NBA) and debates relating

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[2] Among the projects involving displacement funded by the World Bank, large dams account for 63% of displacement (WCD 2000: 104).

[3] According to the WCD, India accounts for 9% of the world's share of dams (WCD 2000: 373).

[4] A recent estimate by Fernandez (2008) concludes that between 1947 and 2000 about 60 million people had been displaced or deprived of their livelihoods due to development projects.

to the Sardar-Sarovar Project clearly point to such outcomes. It is argued that rehabilitation and resettlement of people already affected by the project are lagging behind and is deficient in terms of conformity to international policies and standards, and procedures, and to the decisions of India's own Narmada Tribunal, resulting in "considerable hardships and injustice" to many IDPs (Ramasamy Iyer 2006). The Hindu newspaper of 17 April reports that *"A Brief Note on the Assessment of Resettlement and Rehabilitation (R & R) Sites and Submergence of Villages of the Sardar Sarovar Project"* prepared by a group of ministers noted that many of the current R&R practices are not in accordance with the Supreme Court Decisions (The Hindu 2006). Controversies surrounding the Sardar-Sarovar Project are just a case in point. There are many other water resources development sites where similar controversies prevail. Under the National River Linking Project over half a million people are estimated to be displaced in the peninsular links alone. Many of these studies focus on the short-term consequences of forced displacement and denounce their flaws and impoverishing effects. In contrast, relatively little research has been conducted on the longer-term impacts of relocating communities in newly developed relocation sites with potentially better socioeconomic and physical infrastructure, improved access to support services and enhanced opportunities for improving their livelihoods creating benefits in the longer term that compensate for losses incurred in the short term. The present paper examines long-term impacts of relocation of IDPs in selected water resources development projects in India.

Scope, Objectives and Hypotheses

The present study is limited to an assessment of how the socioeconomic status of IDPs has changed over time. The study examines the long-term trajectories of the displaced communities and identifies factors that play a major role in rejuvenating or constraining their livelihoods in the long run. The focus shifts from reporting displacement traumas to understanding impoverishments and predicting trends that would shed light on how impoverishment risks can be preempted and mitigated in the resettlement and rehabilitation programs. As Thayer Scudder (n.d.) points out there is a clear need for more longitudinal studies of resettled communities because the effects of resettlement carry over to one or two generations.

The focus of this paper is limited to assessing the change over time in the living standards of project-affected people (PAP). The key research question addressed is, has the R&R program enabled the majority of PAP to restore and improve their living standards, or are they more impoverished than before? A related question in cases of positive outcomes is how long did the PAP take to improve their living standards? The principal hypotheses tested are:

a) Adverse short-term impacts of displacement are compensated for by the longer-term benefits generated from enhanced socioeconomic opportunities created in the newly developed relocation sites.

b) With recent refinements in policies and procedures in resettlement and rehabilitation management, short-term adverse effects can be largely arrested, and some even fully prevented, while others are considerably mitigated, and livelihoods of displaced communities restored faster.

If this can be achieved the "long-term positive effects of R&R" would become medium-term positive effects of large-scale infrastructural projects, thus shortening the time in which the investments can be fully justified in many respects.

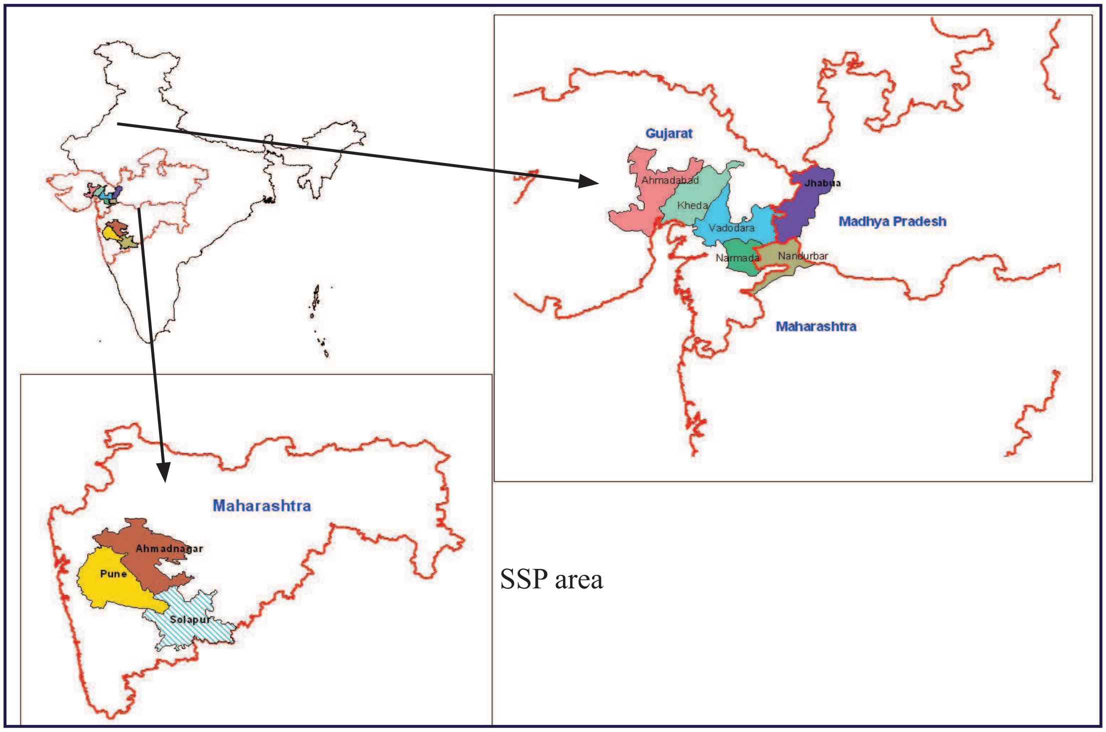
Data and Method

Household Surveys

The hypotheses are tested with empirical data collected from a sample of relocated households in the Bhima-Ujjaini project in Maharashtra and selected locations in the Sardar-Sarovar Project (SSP) area in Gujarat, Maharashtra and Madhya Pradesh (Figure 1).

Construction of the Ujjaini Dam started in 1966 and was completed in 1980. Some 13,500 families from 82 villages in Pune, Solapur and Ahmednagar districts in Maharashtra were displaced and were resettled in 106 relocation sites between 1974 and 1982. This project was selected to study the long-term impact (i.e., > 20 years) on the livelihoods of displaced communities. A sample of 421 families resettled in 20 rehabilitation sites in Solapur and Pune districts was selected for the study.

Figure 1. Location of field sites.



Ujjaini Project – Maharashtra

The SSP is probably the world's most controversial and widely discussed development project. At the current height of 121.92 m, the dam has affected 32,600 families from 300 villages in the states of Gujarat (4,726 families of 91 villages), Madhya Pradesh (24,421 families of 177 villages) and Maharashtra (3,452 families of 32 villages). A sample of 954 displaced households from the three states was selected for the study. The sample consisted of 404 families resettled in 31 rehabilitation sites in Vadodara, Narmada, Kheda and Ahmedabad districts in Gujarat. The Maharashtra sample consisted of 154 households from the Nandurbar district. A sample of 376 households from three districts in Madhya Pradeesh (Barwani, Dhar, Khargone) was chosen for the study. The sample was stratified on the basis of households resettled between 0-5 years, and 5-10 years, and more than 10 years after displacement.

In India, planning and implementing programs for resettlement and rehabilitation of families displaced by infrastructural development projects are the responsibility of the state governments. The households from three states benefiting from the SSP were selected with the aim of comparing the impact of affected by the same project (SSP) but are resettled and rehabilitated under the R&R programs of three different states.

Analysis of Litigations and Submissions to the Grievance Redressal Authority

Litigations filed before the district courts by IDPs were analyzed. A sample of 480 judgments relating to 1,762 litigations filed in the Sholapur District Court, Maharashtra by persons displaced by the Ujjaini Dam project in Maharashtra was analyzed. In addition, summary information on petitions filed by IDPs in the SSP area to the Grievance Redressal Authority (GRA) was also analyzed. The analysis of litigations and petitions to GRC was motivated on the assertion that such information provides a more accurate account of the concerns and difficulties of IDPs than those captured by household questionnaire surveys.

Salient Characteristics of Resettled families

Bhima-Ujjaini Project

Eighty two villages from three districts in Maharashtra were affected by the construction of the dam. According to official statistics, some 13,580 families were affected by the project (Center for Social Sciences 1994). The displaced families were resettled in 106 relocation sites. Official records claim that the process of resettlement that commenced in 1974/75 was completed in 1981/82. At the time of displacement, 58% were agricultural households, 30% employed as agricultural laborers and the rest classified as "engaged in services" and "self-employed." Following displacement, the number employed as agricultural laborers has reportedly increased significantly (Center for Social Sciences 1994). Of the surveyed families, 49% belonged to the backward castes–16% belonged to the scheduled castes, 20% to the scheduled tribes and 13% to other backward castes.

Sardar-Sarovar Project

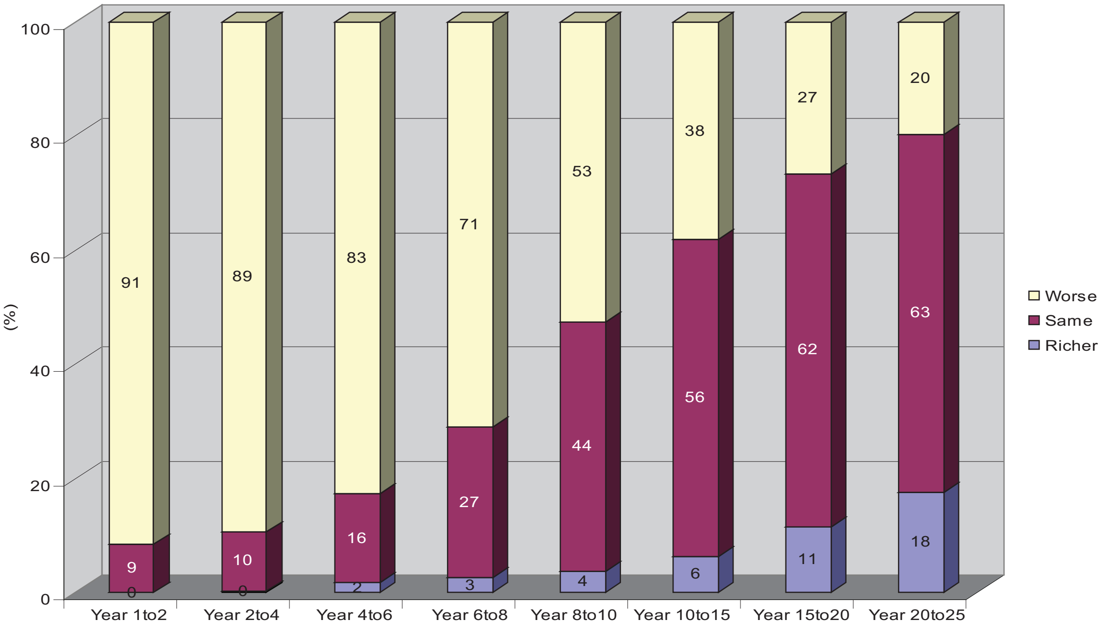
There are no precise estimates of the number of people affected by SSP. Early estimates indicated that the SS Dam would affect some 7,000–10,000 families. Estimates that are more recent claim that about 41,000 families will be affected by the project (Wood 2008). The demography of the families affected is complex. Of the total number of affected families, scheduled castes and scheduled tribes account for a large proportion of the affected families. About 82% of the project-affected people are in Madhya Pradesh (MP), 11% in Gujarta and 7% in Maharashtra. Of these families 97% are tribal people in Gujarat, 100% in Maharashtra and 29% in Madhya Pradesh. The majority of the families are farmers. About 23% of the families in Gujarat and 47% in MP are reported to be landless (IELRC 1995).

Resettlement Outcomes

Three types of outcomes are analyzed where a) a majority of the resettled families have been able to raise their living standards above the level before moving to the new location, b) project initiatives have enabled households to restore their living standards to at least their original level, and c) relocation had worsened their living standards.

Figure 2 gives perceptions of the displaced families of the change in their living standard before displacement and in their current location. A drop in the family's living standard is expected in the years that immediately follow displacement. However, as Figure 2 illustrates, even after 8-10 after resettlement a majority of the PAPs (53%) claimed that they were worse-off than before displacement. Even after 20 years only 18% of the families considered themselves to be better-off than before displacement, while 63% claimed that there was no improvement in the their situation.

Figure 2. Timeline of family circumstances, Bhima-Ujjaini Project.



The inability to restore living standards of the majority of the PAPs at least to their original levels within the first 5 years is a clear indicator of a failed resettlement process. The reasons for such a negative outcome are discussed in later sections.

During the questionnaire survey conducted in the SSP project area PAPs were asked to assess how their family circumstances had changed over time from the year they were displaced to the present. The assessment was made on a scale of +5 to -5 with 0 signifying the living standard at the time of displacement. A rating of +5 indicates a substantial enhancement in the living standard and a rating of -5 a substantial decline. A rating in between these extremes indicates different levels of enhancement or decline in the living standards of the PAPs.

Figures 3a to 3c give PAP's perceptions of changes in family circumstances over time. As Figure 3a demonstrates 59% of the PAPs in Gujarat claimed that they had restored (8%) or enhanced (51%) their standard of living within a period 4-6 years since resettlement. It is also noteworthy that 22% of the Gujarat PAPs claimed to have improved their living standards within the first 2 years. The Gujarat survey results also show that 86% of the PAPs have improved their family circumstances within 10-15 years since displacement from their original villages.

Figure 3a. Timeline of family circumstances, SSP Gujarat.

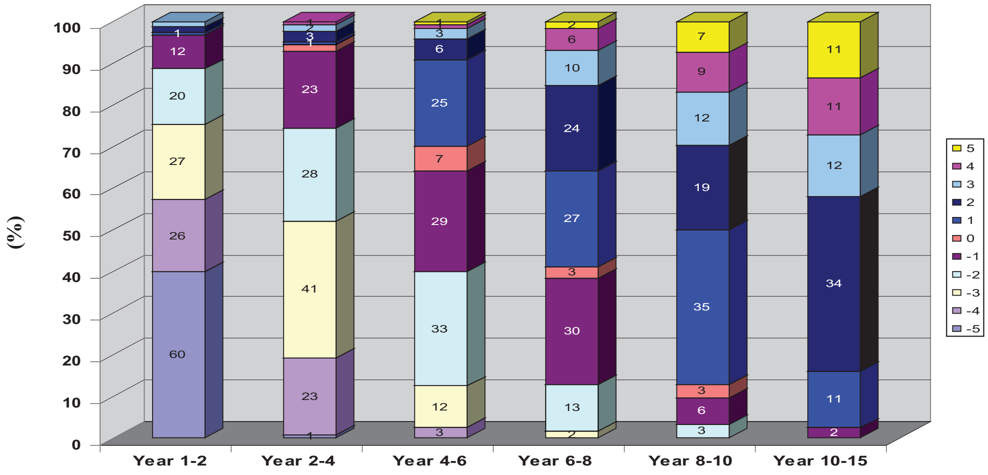


Figure 3b. Timeline of family circumstances, SSP Maharashtra.

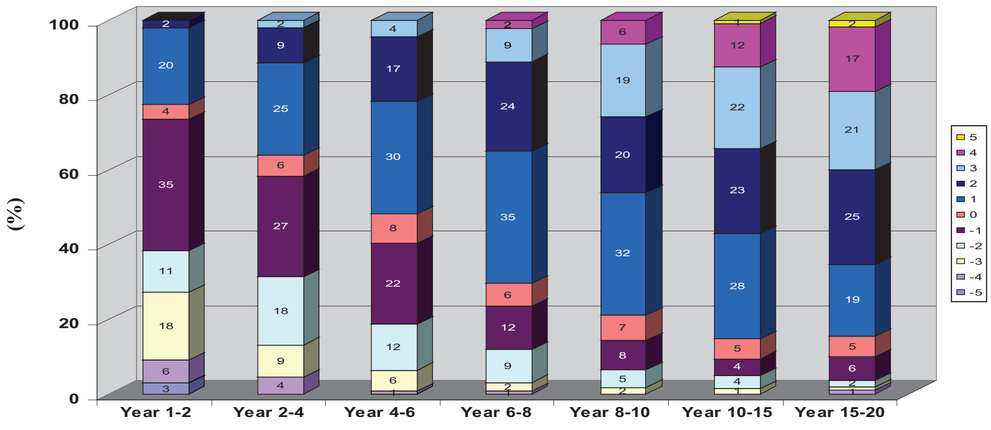
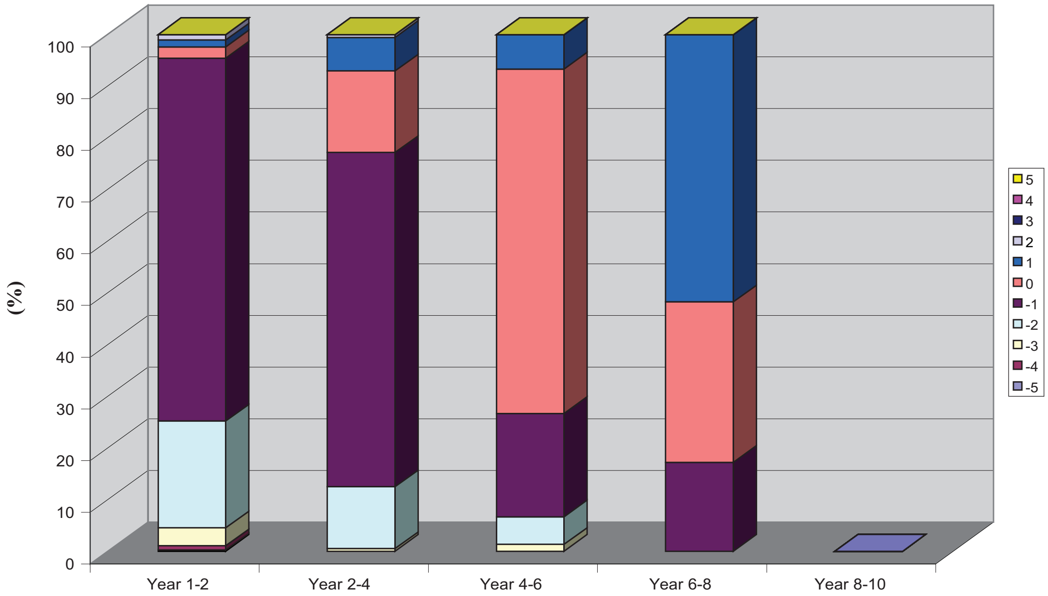


Figure 3c. Timeline of family circumstances, SSP, Madhya Pradesh.



In Maharashtra, 42% of the PAPs claimed that they restored (7%) or enhanced their living standards within 4-6 years since resettlement. By the first 8 years about 75% of them had enjoyed higher standards of living and, by the 15th year, nearly all the sampled PAPs claimed they had raised their living standards after displacement. It took 6 years for a majority of the PAPs to restore their living standards to their former standards.

The achievements in MP in terms of restoration of living standards are much lower than in Gujarat and Maharashtra. The R&R program in MP is ongoing. In the latter sate the majority of the PAPs surveyed claimed that their homesteads have not been fully developed as yet.

Why Successes? Why Failures?

The foregoing analysis illustrates that R&R under SSP had more positive outcomes when compared to Bhima-Ujjaini. However, in the latter case, it was the early experience with R&R conducted at a time when there was no national policy on R&R with hardly any NGOs and civil society involvement to safeguard the rights and privileges of the PAPs, especially of the tribal population and other socially backward groups. In the case of SSP, there has been many improvements in R&R procedures and, for the first time, high standards of R&R have been applied to a project in India (IELRC 1998).

For a deeper understanding of the difficulties encountered by the PAPs, an analysis of the litigations filed before the law courts was reviewed. The analysis was limited to the litigations filed by PAPs of the Bhima-Ujjaini project that has a long history of R&R. The sections that follow summarize the results of the analysis.

Analysis of Litigation Filed by PAPs of the Bhima-Ujjaini Project[5]

The study taken up was meant to understand the difficulties of the PAPs due to the Bhima-Ujjaini project in Maharashtra. Altogether, 480 judgments in respect of litigations filed by 1,762 PAPs were analyzed. The litigations almost exclusively related to problems associated with land acquisition for the project.

The first step in the analysis was to ascertain who the petitioners were, i.e., whether they were large landowners or small farmers and their location. Figure 4 shows the distribution of the petitioners by size of land owned. The number of litigations filed by those owning smaller extents of land, i.e., less than 0.25 ha is comparatively fewer than those owning larger extents of land. Most of the petitioners were from the medium-sized group, i.e. those owning 0.6-3 ha.

Figure 4. Distribution of petitioners according to size of land owned (N = 991).

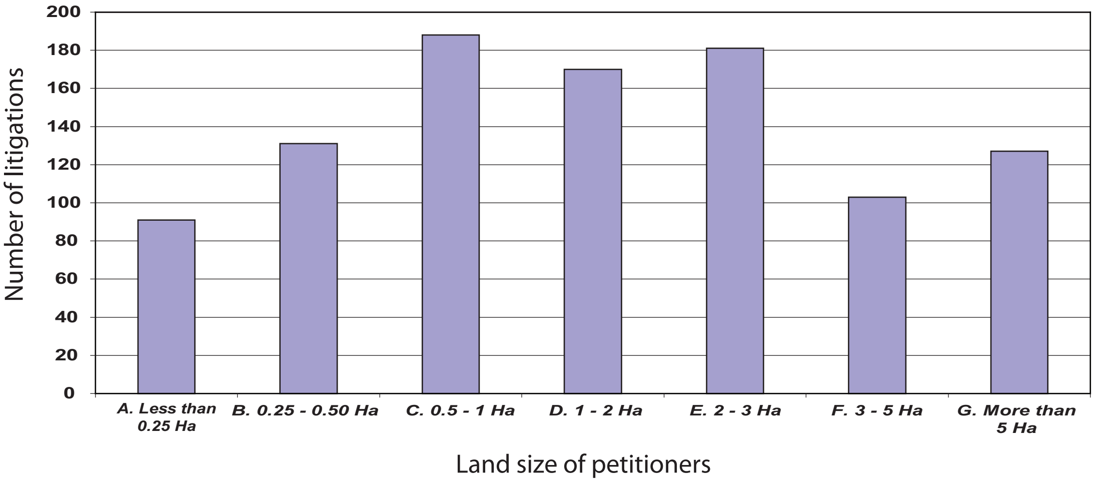


Figure 5 shows that the highest number of litigations were filed from the Mangalwadha *taluk* (subdivision of a district) followed by Karmala. The reasons for the high number of litigations from these two taluks need to be investigated. Figure 6 presents the nature of the litigations filed by the petitioners.

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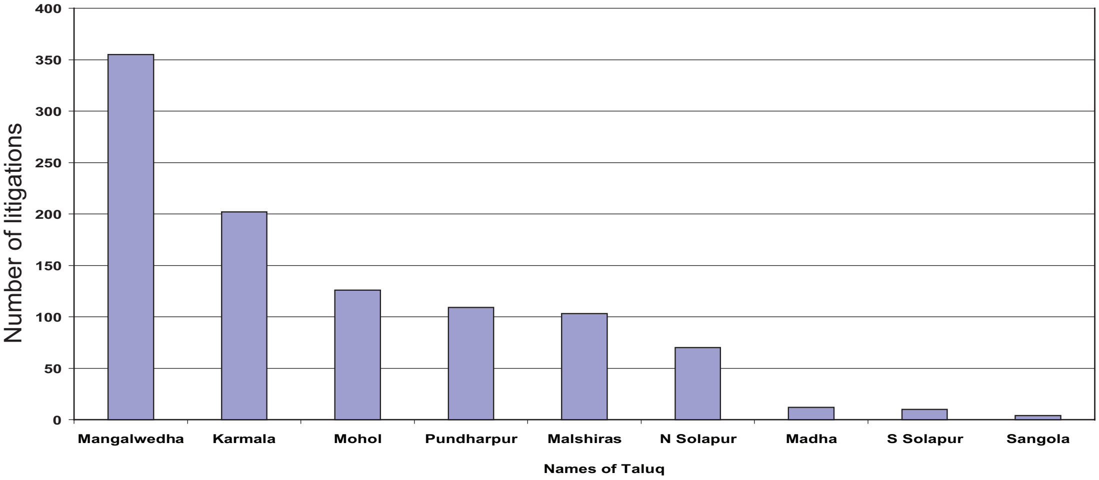
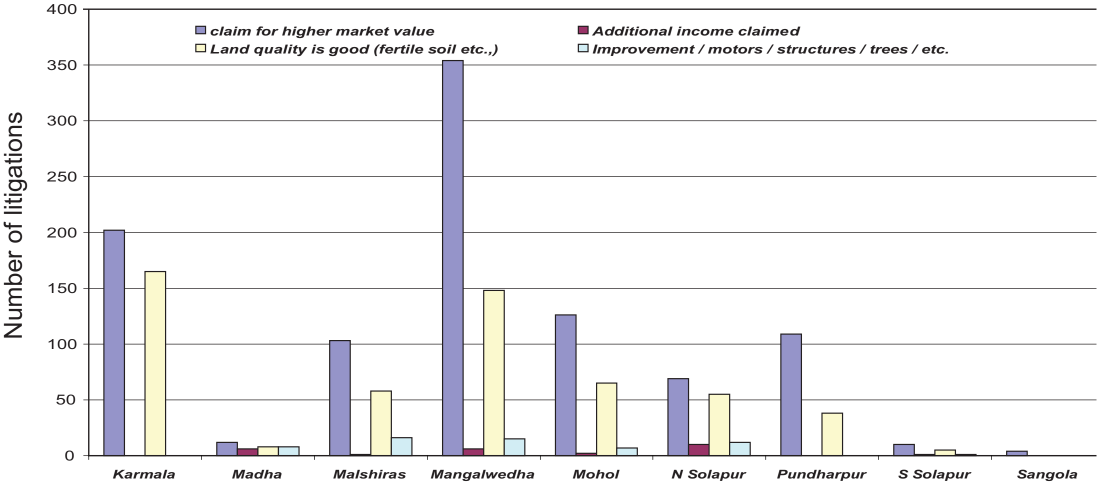
[5] This section was drafted by Professor Madabhushi Sridhar Acharyulu, NALSAR University of Law, Hyderabad.

Figure 5. Distribution of petitioners by taluks.



The majority of the litigations filed are for additional compensation on the ground of the higher market value of the land (figure 6). A second important reason is seeking additional compensation in accordance with the quality of the land.

Figure 6. Nature of the litigations.



Findings

In most of the cases (over 60%) the courts "partly" allowed the claim. This means the market value fixed by the State Land Acquisition Officer was not proper and the claimant proved the entitlement for additional rate of the market value.

Partly Allowed Claims

Where the courts partly allowed the claim, a uniform addition of 30% solatium of excess amount was granted, 9% interest on the compensation from the date of taking possession to the date of final payment (which dates were not made available in the decrees and judgments, due to which it is impossible to know how much of money was exactly increased by the courts) and 12 to 15% interest on the excess amount granted by the courts. Besides the above, there was increase in the rate per hectare in some cases, while an additional amount was paid in some other cases.

Though the place and village were the same and the purpose was acquisition for the Ujjaini Canal, there were varying rates paid to farmers. For example, if an amount of Rs 6,000 per hectare was given by Special Land Acquisition Officer (SLAO), the courts enhanced it to either Rs 9,000 or Rs 12,000. There is enormous variations noticeable in the rates that were fixed by the courts.

The judgments, in general, do not clearly state as to what amount had to be paid to the claimant. Thus, the file goes back to the superintending office of the courts to draw up the Decree to serve as a mandate for the State to pay. It requires again the calculation and payment, which leave a lot of scope for deprivation of farmers due to negligence, miscalculation, dishonesty, etc. In some other cases, the judgment did not give the details of the quality of land (best and ordinary), but fixed different rates for different lands. Thus, it is not possible to arrive at the exact rate of increased payment to farmers. The increase is not uniform, while it is sometimes based on rate per acre, some times just an additional amount.

Rejection of Claims

Where the courts rejected the claims, farmers lost all their rights in addition to delay and the cost of litigation. While winners get 30% enhancement en bloc besides 9% interest and 15% on excess, the losers do not get any thing. The courts justified in each order, the grant of 30% per additional amount as the acquisition was in the nature of ‘compulsion.’ If that is so, even the losers of claims due to lack of evidence to prove increase in value of their land would have been entitled at least to 30% plus 9% plus 15%, (in all 54%) increase in the compensation paid to them by SLAO, which was totally denied to them. In one case, the petition was rejected with costs, which means, the farmer lost the land, time of litigation for more than 6 years, claim, and 54% interest, and burdened with the liability to pay the cost of litigation to the state. It appears to be a travesty of justice.

Difficulties of Proof

Another major problem the farmers faced in the courts of law is that they could not prove that the market value was high as per the standards of proof set by the courts in civil claims. It is the duty of the state to fix a reasonable amount to make it just compensation as per the constitution of India, when it acquires private land for public purposes. It is not possible for a poor, uneducated, uninformed and a novice to know the court procedures, to prove the increase in market value. Second, it is impossible to produce documents regarding increase in market value, in the absence of any transfer of property in the vicinity or village. Third, the law requires not only corroboration for oral evidence but documents, which cannot be produced by a farmer. Because of this, the courts either rejected the claims or partly allowed the claims and only in a few cases was there a total acceptance of claims.

The courts chose to give very elaborate technical and evidentiary reasons to reject the claims fully or partly. The farmers had to lose because of:

a. Wrongful and arbitrary fixation of low rates by the SLAO.

b. Lack of evidence of increase in market value.

c. Lack of sales transactions in the past in the village or the vicinity.

d. Technical rejection of the total claim.

e. Lack of understanding of the plight of farmers by the lower judiciary.

f. Technical rule adherence of the judiciary, depriving the farmers whose claims were rejected while a 54% common increase was allowed to all of those where the claim was partly allowed.

Gross Injustice in Rejected Cases

In most of the cases rejected by the courts, the farmers were made to pay costs to the government for "bringing unnecessary claims." It is very unreasonable and not justified at all. Their failure in proving the enhanced value is due to several technical reasons. If one takes the overall conclusion of the cases the farmers' dissatisfaction was upheld and the fact that they were paid lesser amounts was proved. In such cases, how were the farmers penalized for bringing an action against the state for just compensation?

The major reason for rejecting the claims is the lack of proof of the market value. As there was no sale transaction in a particular area, it was difficult for the poor farmer to produce evidence for the assumed market value. It is such a situation that unless there is a sale, there is no document to establish the value. In the absence of sale the value could not be proved. Though it has its own market value, the simple fact of absence of a transaction deprived several of the farmers of their real worth of the property that was lost. In many cases, the courts did not take into account the loss of future gains, which unfortunately was not claimed by any applicant. The fact that the land was the livelihood was totally neglected by the applicants because of their lack of awareness, and even by their lawyers, may be because of negligence or inefficiency. It is so unfortunate in no case out of 480 that went to the courts, was the issue of land as livelihood either mentioned or discussed. At the end, the courts did not find any material before them to enhance the compensation to adequate levels. Around 252 farmers could not get anything in spite of their struggle in litigation as their cases were not accepted.

In most of the cases where they lost, their poverty made them to lose. Because they could not utilize the land by adding water sources or raising some structures or planting profit-yielding gardens, etc., they could not enhance the value of the land.

The fight in courts of law appears to be very unproductive and the time and money spent on the litigation is comparatively very high in relation to the raise in compensation yielded. In one case it took 23 years just for one step of litigation wherein 13 parties together gained an increase of just Rs 4,873 more than what was given by the SLAO. In another case, one applicant got just Rs 1,508 after 22 years' long litigation. Most of the cases were rejected after 10 or 15 years of hearing. While just 23 cases were completed within 1 year, 339 cases were disposed of within 2 to 7 years while 120 cases took more than 8 years for disposal.

When the SLAO fixes the amount of compensation in the beginning itself, the villagers of the Sholapur District would have had no need to come to courts of law for enhancement. It is because of the inefficiency or negligence of SLAO that the farmers were either paid less or driven to courts of law, while they were deprived of their right to just compensation within a reasonable time frame. This fact is well established through the observations of the judicial officers that the compensation fixed by the SALO was inadequate and unreasonable. The inefficiency of SLAO was amply proved as it was only in two out of 480 cases that the courts found the compensation as adequate. Though there were a number of rejections and dismissals they were based on the lack of evidence and not because of the adequacy of compensation fixed by SLAO.

Who Has to Calculate the Just Compensation?

It is the duty of the state, which compulsorily acquired the land of the farmer to provide just compensation. This is the constitutional principle. Then how can the courts impose the burden on the farmer who has neither education, nor means to know the real value of his land?

There is a lot of difference between a civil case where compensation is demanded for a violation of right, necessitating the claimant to prove what loss he had suffered, and a civil case where land was compulsorily acquired. In the latter case it is the responsibility of the state to calculate and give just compensation; it is not possible for the farmers to prove the exact rate of compensation. The courts also could not help the farmers to get just compensation because of their habitual technical approach resulting in procedural injustice. The courts should have not insisted on cent per cent evidence for establishing claims.

Where the farmers wanted the enhanced value of land to be taken into account, the courts just increased a little amount, because they could not believe the claims as they were not supported by any documents. The courts generally did not look into the point that it was not possible for farmers to prove the value of their land, quality of their land and annual returns with documents.

There are some more aspects that need to be considered with reference to just compensation which is beyond the comprehension of land acquisition law, land acquisition officers, and the courts caught in the cobweb of procedural tangles, which are as follows:

1. The Ujjaini Canal has improved the value of the land, prospects of productivity of land in the vicinity. But some farmers lost their total land while others lost part of their own land. Neither SLAO nor the courts have taken into account the prospective increase in value of land, its productivity while fixing and adjudicating on the rate of the land.
2. While some farmers lost the land for the Ujjaini Canal, other farmers gained as their livelihood was strengthened, economy was improved and market value increased. If they proposed to sell the land after Ujjaini Canal started irrigating their lands, they would have got more than a hundredfold increase in the market value, which factor was never considered regarding farmers who lost the land.

3. There is an enormous increase in the land value with the real estate boom everywhere, which helped those whose land was not acquired while those who lost suffered most.
4. The owners of land were not uprooted and removed totally from the village while the roots of other farmers whose lands got watered were strengthened. There is neither logic nor justification in ruining some farmers by uprooting them and benefiting others based on the sacrifices inflicted on people by the state.
5. The farmers who approached courts for enhancement of compensation for acquiring their entire land were not given alternative land in compensation. They were also not given any house or any other compensation except an arbitrarily fixed amount.
6. The farmers, who lost their land because of the canal, should have been given some land if not equal to what they lost, so that they also could take the benefit of development in the shape of the new irrigation project, in this case Ujjaini Canal.
7. The farmers, who lost their land, were in fact, provided infrastructure to the Ujjaini Canal, and should have become shareholders in the development that resulted from that project. If a piece of land in urban areas is given for development of apartments, the landowner would have got more than the mere cost of the land as per contemporary rates. For example, if a builder constructs 10 apartments in a plot of land of 400 square yards in an urban area, the owner would get four or five flats to his share while the farmers in the rural area would lose much larger tracts of land and to develop the value of the land in the entire region, they would not get anything more than the pittance paid as "compensation."
8. The farmers were put to unnecessary tension, delay, expense, emotional stress, monitory losses, etc., for no fault of them.
9. There is no integrated approach from the state to provide alternative livelihoods to the farmers whose only source of livelihood, i.e., land, is removed from them.

Enhancement

Enhancement is made when the claimants produce the deeds of sale of nearby lands acquired, and ascertained as the prevailing value which was in variation with the price fixed by the Special Land Acquisition Officer. The courts found it easy to enhance the compensation only in these cases. The full claim was allowed only in a few cases, while it granted additional compensation, solatium or costs, etc.

The courts also took into notice the value-additions made to the land where it was proved that an irrigating well was present, land was of high quality, or seasonally irrigated as they are considered *bagayat, zirayat* class of lands or black soil, etc., which yielded additional amounts. The courts also considered the developments made by the claimants before acquisition while it valued the profit-yielding trees, crops, other woods, electric motor pump sets, sheds and other constructions like rest rooms, etc.

As the complete data are not available regarding the total land the farmers had and the percentage of the land they lost in acquisition, it is not possible to say whether 1,762 farmers lost their total land which meant their means of livelihood.

Grievances of People Affected by the SSP Project

Table 1 gives the submissions made by PAPs with regard to problems relating to R&R under SSP. Out of the 22,437 submissions 14,824 or 66% relate to land acquisition matters. This suggests that the problems related to land acquisitions as those prevailed under the Bhima-Ujjaini project for some 30 years, as discussed in the previous section, continue to persist even under the recent R&R program such as those under SSP.

Table 1.The submissions made by PAPs with regard to problems relating to R&R under SSP.

(As on 30/06/2007)

Jurisdi-ction	Grievances					Redressed grievances		Pending grievances
	Civic amenities	Land	Others	PAP status	Total	Total	%	
Gujarat	1,123	8,751	759	3,734	14,367	13,319	92.71	1,048
Maharashtra	239	1,540	122	217	2,118	1,981	93.53	137
MP	434	4,533	504	481	5,952	5,667	95.21	285
Total	1,796	14,824	1,385	4,432	22,437	20,967	93.45	1,470

Concluding Remarks

Despite several decades of experience, R&R of IDPs continue to be a difficult problem also despite the vast national and international experiences in R&R and the existence of several guidelines on resettlement management. One of the major reasons of apparent failures of R&R is that most studies focus on bad R&R experiences and denounce their flaws and impoverishing effects. The focus is on short-term consequences and immediate impacts. Displacement is a painful process and every effort should be taken to avoid or minimize disrupting people's lives to the maximum extent possible. At the same time, relocating people also provides them with new opportunities which require time. As stated in the judgment handed down by the Supreme Court in the Narmada Bachao Andolan Versus Union of India & Others case on 18 October 2000 "*R&R packages of the States, specially of Gujarat, are such that the living conditions of the oustees will be much better than what they had in their tribal hamlets.*"

As pointed out earlier in this paper, R&R constitute a long-term proess that may take several years to restore and enhance the living standards of persons displaced. The essence of good R&R is to minimize relocation stresses and expedite the restoration of disrupted livelihoods. In this context, the results of this study show that R&R under SSP have been at a higher level than most other R&R efforts. The Gujarat experience merits attention as it puts in place unique mechanisms for replacement of agricultural land at market prices and setting up a separate unit for coordinating and managing R&R.

Finally, there is a clear need for longitudinal studies on R&R programs. There should be a stronger commitment to active engagement to preempt impoverishment risks and take remedial measures, rather than passive contemplation in the flaws of R&R programs and their impoverishing effects.

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Promoting Demand Management in Irrigation in India: Policy Options and Institutional Requirements

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Introduction

The symptoms of an ever-growing gap between water supply and demand, already visible in a few regions around the country, are soon expected to assume national proportions and become a permanent feature of the Indian water economy. While water demand is growing fast due to population growth and economic expansion, water supply is not growing at the same rate due to constraints in expanding supply and also due to the ultimate physical limit for supply expansion. Although water resources developed at present, i.e., 644 billion cubic meters (Bm^3), constitute only 57% of the ultimate utilizable potential (1,122 Bm^3), augmenting supply beyond this level is going to be increasingly constrained by investment bottlenecks, environmental concerns, and political and legal snags. In this respect, the country's ability to meet the increasing water demand in the next few decades will be a major challenge. According to the Ministry of Water Resources (2000), the total demand is projected to increase to 694-710 Bm^3 by 2010 to 784-850 Bm^3 by 2025 and to 973-1,180 Bm^3 by 2050. A recent analysis of water demand and supply scenarios, which accounts for the major changes in the key drivers of water demand and supply, also confirms this demand trend (Amarasinghe et al. 2007a). Particularly, this study projects that under the 'business-as-usual' water use patterns, nine basins amounting to over four-fifths of the total water use in India, will face physical water scarcity by 2050.

From a larger perspective, water scarcity of this magnitude will constrain the ability of the country in meeting the increasing food, livelihood, and water supply needs of an increasing population. Such an inability for a monsoon-dependent and rural-based economy such as India is likely to have devastating social, economic, and political consequences unless water demand is managed through well-designed and implemented policies for improving water use efficiency and productivity, particularly in the irrigation sector, which accounts for the most water consumption. As the scenario facing the Indian water economy is rather grave, any

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policy prescription would obviously call for a radical change in the development paradigm governing water resources development, allocation, and management. Supply-side solutions based on physical approaches towards supply augmentation and system improvement, though essential in certain contexts, cannot be the exclusive basis for water-sector strategies. A paradigmatic shift is needed for seeking durable solutions rooted in water demand management options, particularly in the irrigation sector that accounts for more than four-fifths of the total water withdrawals in the country. It is even more important as we consider the fact that the consumptive use fraction of the irrigation deliveries at present is only about 40% (Amarasinghe et al. 2007b).

The demand management options that we consider here for evaluation are well known in literature and practice on water policy. These options include water allocation and management tools such as: (a) water pricing policies that cover both the level and structure of water rates and also the criteria used for fixing them; (b) formal and informal water markets occurring at the micro and macro levels; (c) water rights and entitlement systems for setting access and volumetric limits; (d) energy-based water regulations such as power tariff and supply manipulations; (e) water-saving technologies that cover drip and sprinkler systems as well as crop choice and farm practices; and (f) user and community-based organizations, covering water user associations, a *panchayat* (an elected governance body at the village level), and informal community groups. Although adoptions of these options are critical, what is more critical is the creation of the supportive institutions to ensure their operational effectiveness and water saving performance.

Objectives and Scope

While the importance of demand management options can hardly be disputed, there are still a number of questions that are to be answered from a practical policy perspective in the context of each of the six demand management options. For instance, what is the present status of these options in the irrigation management strategy in India? What is the extent of their application? How effective are they in influencing water use decisions at the farm level? Are there active policies in promoting them at the national and state level? Are there cases of success and best practices in demand management? If so, what are the lessons for policy in upscaling them? What are the bottlenecks and constraints for promoting them on a wider scale, particularly within the irrigation sector? What are the present potentials and future prospects for these options as an effective means for improving water use efficiency and water saving, which are sufficient enough either to expand irrigation or to reallocate water to nonagricultural uses and sectors? To explore these and related questions in the context of each of the six demand management options, IWMI has commissioned six separate papers[2] prepared by some of the leading experts on the Indian water sector. These papers were prepared with a common analytical structure to specifically address some of the most relevant practical questions and policy issues (see V.R. Reddy 2008; Palanisami 2008; Narain 2008; Malik 2008; Narayanamoorthy 2008; M. V. Reddy 2008).

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[2] These papers were commissioned in phase III of the IWMI project, ‘Strategic Analyses of India’s River Linking Project,’ under the aegis of the Challenge Program on Water and Food. Phase III of the project explores the options that contribute to an alternative water sector perspective plan, in case supply augmenting strategies such as the National River Linking Project (NRLP) will fail to meet the increasing water demand.

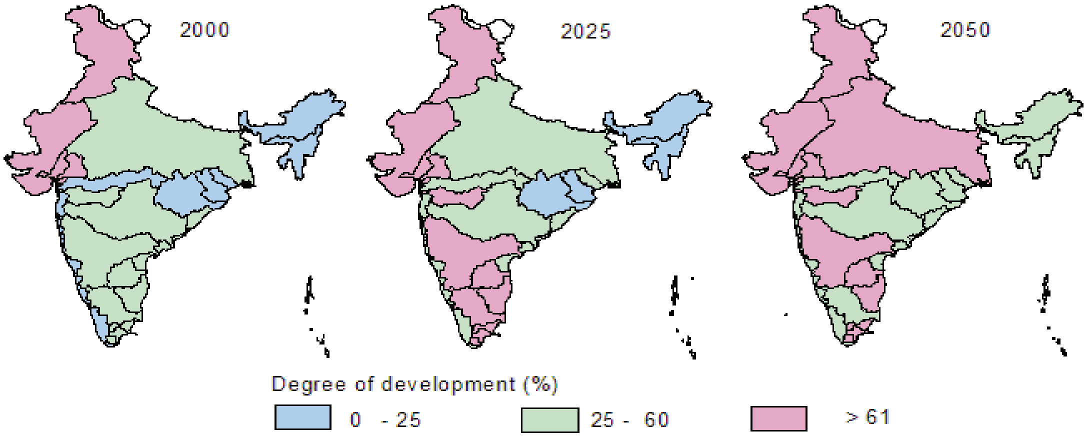
The main purpose of this paper is to: (a) set the basic economic logic of demand management options; (b) provide an overview and a synthesis of the option-specific papers prepared by experts; (c) indicate the key differences and common features emerging from the practical experiences of the demand management options; (d) present an analytical framework that will help understand the operations and linkages among the demand management options and their underlying institutional elements; (e) outline a generic strategy that can better exploit the inherent synergies among the demand management options and align them with the underlying institutional structure and environment; (f) discuss how such a strategy can be effectively promoted within the technical, financial, institutional, and political economy constraints; and (g) conclude with practical insights and policy implications of the discussions in this synthesis paper and in all the six option-specific papers. As to the focus, the discussion on demand management options is specifically confined to the irrigation sector. However, the general implications, especially those related to the institutional dimensions, can also pertain to demand regulations in other sectors, though the relevant options may be different.

Demand Management Options: Logic and Focus

Although the adoption of demand management options on a wider scale is slower than needed, given the changing water supply and demand realities both at the national and local levels, an increasing reliance on these options is inevitable, especially in the irrigation sector and in basins where physical water scarcity is already evident. Considering the predominant share of the irrigation sector in total water use and the small consumptive use factor of irrigation withdrawals, the potential of this sector for water savings and efficiency gains from demand management options are obviously immense. Similarly, larger basins with excessive water withdrawals for agricultural uses also offer a better scope for achieving use efficiency and water savings. Besides their implications for the scope and focus of demand management, the current and prospective physical and economic realities of the water sector also provide the basic rationale for promoting demand management options and strategies.

The total water withdrawal for all uses at the national level in the year 2000 was estimated to be 680 Bm^3 (Amarasinghe et al. 2007b). But, if the 'business-as-usual' path of water management and water use pattern continues, water demand is expected to increase by 22% by 2025 and by 32% by 2050. With such a demand growth, more and more basins are likely to face physical water scarcity, i.e., water withdrawal exceeding 60% of the potentially utilizable resource. Since withdrawal exceeding this level is expected to be both financially costly and environmentally difficult, more basins are also likely to face economic or financial water scarcity as well. As can be seen in Figure 1, many basins in India are expected to be in this predicament of physical and financial scarcity by the year 2050, if not earlier. As these basins account for close to three-fifths of the country and cover agriculturally most important basins, including the Indus, Ganges, Cauvery, and Krishna basins, they will have a pernicious effect on the food and livelihood as well as political fronts.

Figure 1. Degree of development of Indian river basins.



Note: If the degree of development-- the ratio of primary water withdrawals to potentially utilizable supply—exceeds 60%, a basin is physically water-scarce. If the additional demand exceeds 25% of the present level, the basins are economically water-scarce.

Source: Amarasinghe et al 2007b

As can be seen in Table 1, which depicts total water withdrawals by use, source and basins in 2000, the irrigation sector accounts for 89% of the total withdrawals at the national level. Such a dominant share of irrigation is also evident in most of the basins. Despite such a large share of water withdrawal, the actual consumptive use—the portion that is actually used for the net evapotranspiration of crops—is only 41% at the national level. The fraction of consumptive use varies from 12 to 59% across basins, depending obviously on factors such as crop and land use patterns as well as irrigation efficiency at project and farm levels. It is the difference between this consumptive use and the total water withdrawal that provides the physical basis for achieving water use efficiency and water savings through demand management both at the national and basin level. Admittedly, it will not be possible to realize this entire potential for water savings due to various physical, technical, economic, and institutional reasons. But, it is certainly possible to achieve, say, 20% of this potential water savings with proper targeting of regions for concerted demand management policies and investments.

In view of the possibility of greater technical control over the volume and use, the scope for realizing water savings is more in groundwater areas than in surface water areas. Notably, in groundwater areas, where irrigation efficiency is already higher than in canal areas, further efficiency improvements are possible, that too, mainly through policy and institutional changes. In contrast, efficiency improvements require mainly technical changes, especially involving a massive redesign of water conveyance and delivery systems, though policy and institutional changes are also essential to enhance and sustain the efficiency gains. As a result of their differential policy and institutional requirements, efficiency gains are relatively more immediate in groundwater areas and would also involve relatively smaller public investments on physical structures. Using this fact taken with the dominant (i.e., 60%) share of groundwater in total irrigation, it is possible to realize the overall irrigation efficiency targets with greater attention on the groundwater areas, particularly those with severe depletion problems.

Table 1. Water withdrawal by use, source and basins, 2000.

River basins	Water withdrawal			NET[3] as % of irrigation withdrawal	Gross irrigated area		Groundwater abstraction ratio[4]
	Total[1]	As % of potentially utilizable resources[2]	Share of irrigation		Total	Groundwater share	
	Bm^3	%	%	%	Mha	%	%
Indus	98	135	96	37	11.6	58	67
Ganga	285	68	90	41	36.5	69	56
Brahmaputra	6	12	67	14	0.4	14	4
Barak	3	29	76	12	0.3	6	4
Subarnarekha	3	35	81	24	0.4	46	36
Brahmani-Baitarani	6	28	88	24	0.7	28	21
Mahanadi	21	32	92	24	2.2	20	13
Godavari	44	37	85	46	4.3	59	40
Krishna	55	66	89	45	5.2	44	48
Pennar	8	66	90	47	0.7	65	61
Cauvery	22	70	85	39	1.9	48	43
Tapi	9	41	81	55	0.8	80	59
Narmada	13	30	90	46	1.5	61	42
Mahi	6	89	86	43	0.5	55	44
Sabarmati	7	136	86	53	0.9	83	100
WFR1[5]	29	112	88	59	3.2	89	132
WRF2[5]	14	26	52	34	0.9	40	22
EFR1[5]	20	63	92	35	1.9	26	17
EFR2[5]	33	95	86	37	2.2	54	46
All basins	684	61	89	41	75.9	61	48

Source: Amarasinghe et al. 2007b.

Notes: [1] Total includes withdrawals for irrigation, domestic and industrial sectors.

[2] Figures more than 100% also include recycling.

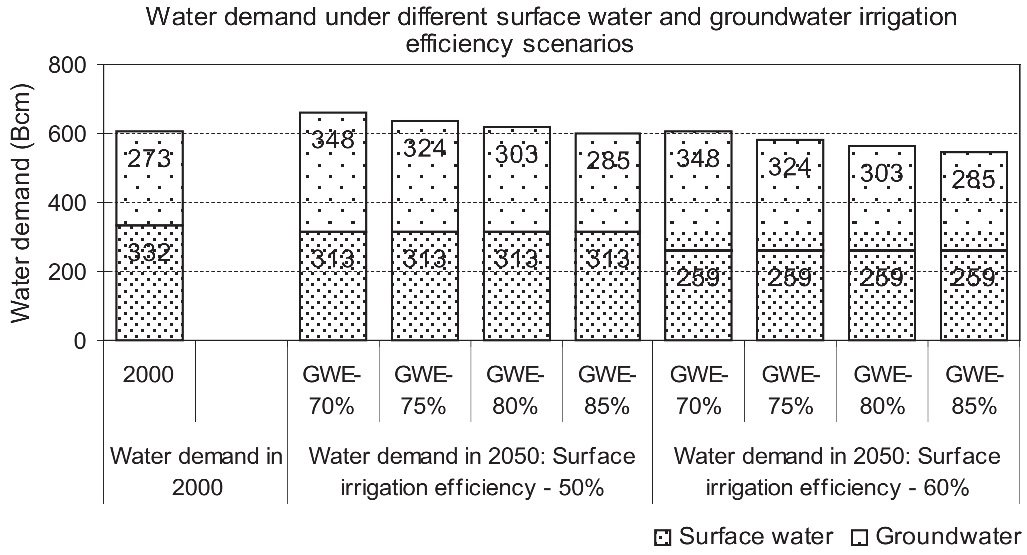
[3] NET is the net evapotranspiration of all irrigated crops.

[4] It relates total groundwater withdrawals to the total groundwater availability through natural recharge and return flows .

[5] WFR1 comprises west-flowing rivers of Kutch, Saurashtra and Luni; WFR2 comprises west-flowing rivers from Tapi to Kanayakumari; EFR1 comprises east-flowing rivers between Mahanadi and Pennar, and EFR2 comprises east-flowing rivers between Pennar and Kanyakumari.

Besides their immediate impacts on agricultural productivity, improvements in irrigation efficiency will also have a direct effect on the irrigation water demand and, hence, on the water savings necessary for meeting urban and environmental needs. As can be seen in Figure 2, if the overall irrigation efficiency in canal regions can be raised from the current level of 40 to 50% and in the groundwater regions from the present level of 60 to 80%, the future irrigation demand, even with the larger irrigated area, will not exceed the present level of agricultural water withdrawals. But, if the surface irrigation efficiency is increased by an additional 10%, i.e., to 60%, while keeping groundwater irrigation efficiency at 80%, there will be a reduction in irrigation demand to the tune of 43 Bm^3 (Amarasinghe et al. 2007b). If it is possible to raise groundwater irrigation efficiency by an additional 5%, i.e., 85%, then, the total reduction in irrigation demand can be as high as 63 Bm^3. Notably, this reduced irrigation demand or irrigation water savings are close to the total nonirrigation demand in 2000, i.e., 79 Bm^3. In a sense, this represents the true magnitude of the potential for water savings that exists in the agriculture sector at present. This potential can be realized gradually through the implementation of demand management strategies involving the judicious application of options such as water pricing, water markets, water rights, energy regulations, water saving technologies and user associations.

Figure 2. Irrigation efficiency and water demand scenarios.



Note: GWE – Groundwarer irrigation efficiency.
Source: Amarasinghe et al. 2007b.

The immediate goal of demand management is not only the reallocation of water away from irrigation but also to set the conditions for a long-term improvement in the productivity and efficiency of irrigated agriculture. In fact, an excessive focus on water reallocation often creates resistance and constraints for the promotion of the demand management options. In reality, the improving efficiency is the most immediate and central goal, whereas the reallocation is only a secondary goal, which flows as an outcome of the former, that too, within a voluntary and compensation-based incentive framework. This point, though seeming to be simple and hence, remains often underestimated, is rather crucial, especially from a political economy perspective of creating the necessary economic and institutional conditions for the application of demand management options.

The macro-logic for demand management is clearly underlined by the increasing water supply-demand gap at the national level. There are also other equally compelling reasons—both the macro and micro ones—for the urgency of promoting these options in Indian agriculture. One of them relates to the food and livelihood implications (see Palanisami and Paramasivam 2007). The total food grain area in India has increased about 1.2 times between 1950 and 2005, i.e., from 97 million ha (Mha) to about 121 Mha whereas the food grain production has increased by 4.1 times, from 51 million tonnes (mt) to 208 mt (GOI 2007). Irrigation has been a major source of determinant for the productivity increase, where the irrigated area under food grains has increased by 3.0 times, from 18 to 54 Mha between 1950 and 2005. Over the same period the total or gross irrigated area has increased by 3.6 times from 22 to 80 Mha. This shows that while irrigation has been playing a major role in increasing food grain productivity and production, the demand for irrigation for non-grain crops is also increasing.

It is expected that the water demand of non-food grain crops will further accelerate with changing consumption patterns (Amarasinghe et al 2007a,b). This, along with the increasing water demand of domestic and industrial sectors will have significant implications for increasing food grain productivity and the food security of India. For instance, given the current level of food consumption and the expected population of around 1.6 billion, India is projected to have a food grain demand of about 400 mt—about twice the present food production—by 2050. Unless an increase in water productivity is realized, meeting this food demand would entail the provision of irrigation to an additional 60 Mha more than the current irrigated area. The expanded level of irrigation required to meet the food security targets is clearly impractical to achieve through the usual approach of supply augmentation because of the double whammy effects coming from the binding limits for adding new supplies and the increasing inter-sectoral competition over existing supply itself.

A much more potent argument against the additional allocation for irrigation however, comes from the serious magnitude of water use inefficiency found within the irrigation sector itself. It is a well-known fact that the average water use efficiency is rather low in irrigation, ranging from 40% in the canal regions to about 60% in the groundwater regions (see Amarasinghe et al. 2007a). Such a magnitude of water use inefficiency does suggest the existence of a hidden irrigation potential and such a potential can be realized with improved efficiency in water application, as achieved through the use of demand management options. Simplified estimates, made a few years ago, suggest that it is possible to effect a 10 to 20% improvement in water use efficiency, on an average, over a 5-year period and such improvement would release an additional 10-20 Mha of irrigation potential within the existing level of water use (Saleth 1996). This is very close to what is achieved in an entire 5-year plan period through new supplies obtained with spending so much time and investment. If this time and investment spent on the supply-side solutions are redirected towards the demand-side options, it is equally possible to irrigate more areas with the same or, even, a reduced level of water use. This indeed is the central logic for promoting the adoption of demand management options. What is needed, therefore, is not a fringe investment on demand management but rather a major policy and investment shift from supply augmentation to demand management.

As to the focus and coverage, some of the demand management options are context-specific, whereas others are applicable in a more generic context. For instance, water pricing is a tool that is largely applicable to canal regions, whereas the option involving energy regulations—involving both supply and price manipulations—is largely applicable to groundwater contexts, though they may also be relevant in canal regions to the extent water lifting is involved there. This is also true in the case of the options involving both the water markets and water saving technologies, as they occur predominantly in the groundwater regions.[3] But, the options involving water rights and user associations are relevant in the context of both canal and groundwater regions. Similarly, some of the options are more direct and immediate in their impacts on water demand, while others have an indirect and gradual effect and, that too, depending on a host of other factors. For instance, water rights and water saving technologies have a more direct effect on water demand, and the options involving user associations and energy regulations only have an indirect effect.

More importantly, the demand management options also differ considerably in terms of the scope for adoption and implementation, especially from a political economy perspective. Among the options, water rights system is the most difficult one followed by water pricing

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[3] The water saving technologies using micro-irrigation—sprinklers and drip—are rare in canal command areas. However, there is evidence that sprinkler irrigation can be adopted in conjunction with intermediate water storage structures in farms (Amarasinghe et al. 2008). There is also evidence that aerobic rice and system of rice intensification can also be used as demand management strategies for saving water in rice cultivation.

reforms and energy regulations, but those involving water markets and user associations are relatively easier to adopt, though their implementation can still remain difficult. Water saving technologies, though politically benign and not controversial, still require favorable cropping systems and effective credit and investment policies. The differences in their application context, political feasibility and the gestation period of impact are very important and should be understood because such factors will determine the relative scale of application and the overall impact of the demand management options.

Demand Management Options in India: An Overview and Synthesis

Before developing the analytical framework that sheds light on the strategic and institutional dimensions as well as the dynamics and impact paths of demand management, it is useful to provide an overview and synthesis of the six demand management options (V.R. Reddy 2008; Palanisami 2008; Narain 2008; Malik 2008; Narayanamoorthy 2008; M.V. Reddy 2008). Since these papers provide a comprehensive evaluation of the present status and effectiveness of the individual demand management options in the particular context of the irrigation sector, an overview of them can be helpful both to highlight the main issues and challenges and to explore the possible avenues for enhancing the individual and joint coverage and demand management performance. With this point in mind, let us provide a quick overview and synthesis of the potential, present status, problems and prospects of individual options as presented in each of the option-specific papers.

Water Pricing

V.R. Reddy (2008), in his most comprehensive review of water pricing as a demand management option, concludes that the ability of water pricing to influence water use in India is severely constrained both by the nature and level of water rates and by the lack of effective institutional and technical conditions. Although successive Irrigation Commissions have recommended to base water rates on benefits or gross revenues rather than on simple provision costs, the prevailing rates in most states are tuned more to cost recovery than to income or benefits. Even this cost focus is also restricted to operation and maintenance (O&M) costs, and in most states the water rates were able to cover no more than 20% of these costs. Notably, V.R. Reddy (2008) argues that such lower rates are more to do with technical and political factors than with issues on willingness to pay, as the case of farmers willing to pay more, especially with an improved supply and service quality, is well documented across the states.

Besides the lower level, the nature and structure of water rates also make them ineffective both in their cost recovery and allocation roles. Since water rates are charged in terms of area, crop and season (or combinations thereof), they fail to create enough incentive for water use efficiency. While water rates in groundwater areas are relatively higher, they are also related to average pump costs rather than to water productivity or economic value (see V.R. Reddy 2008, Table 3). Under this condition, it is far-fetched to expect the present water pricing policy to play the much needed economic role of water allocation. Based on a careful review of both water pricing literature and actual experience in India and abroad, V.R. Reddy (2008) argues that water pricing policy can be an effective tool to manage demand, if it is designed within a marginal cost principle, volumetric allocation and block or tier structure. Besides the design aspects, he has also elaborated on supportive institutional conditions such as the user associations, locally managed water rights, water markets and system redesigns to improve conveyance and delivery.

Although Indian experience shows that water pricing is largely ineffective in influencing water use, there are interesting examples, which, in fact, show the importance of the necessary technical and institutional conditions. While water pricing has not been that effective, its effectiveness can be enhanced with the proper level and structuring of water rates. For instance, in Israel, marginal cost pricing followed within either the block rate structure or the tier rate system has been successful in reducing water consumption by 7%. Similarly, pricing policy, when combined with supply regulations either directly or through water rights, can also be very effective. For instance, the Krishna Delta farmers in Andhra Pradesh received 40% less than the normal supply during the drought of 2001-2004. Interestingly, they have not only managed well with this lower supply but also reported a 20% improvement in the yield (V.R. Reddy 2008). Although this case shows the efficiency and water saving benefits of an accidental supply reduction during drought, it does demonstrate the potential of direct supply regulations in canal regions. The experience in cases such as Australia and California in the US shows that the effectiveness of water pricing in demand management can be attributed to the supporting institutions such as volumetric allocation, water rights and water markets.

Water Markets

In his critical review and evaluation, Palanisami (2008) highlights both the opportunities and challenges involved in using prevailing water markets as a demand management option in irrigation. He has compiled extensive empirical evidence on the efficiency and equity roles of water markets both in the groundwater and tank regions. But, at the same time, he also notes the negative social and resource effects due to the monopoly tendencies and groundwater depletion. While there is scope for considerable net positive effects of water markets on water use efficiency, he reckons it to be rather small for two major reasons. First, although water markets are observed widely, the areas they cover or influence are small and they occur mostly in groundwater regions mainly on a sporadic basis. The estimated area served or *influenced* by water markets varies widely in a range of 15 to 50% of the total irrigated area in the country. But, given their seasonal character, transitory nature and concentration in a few regions, the actual area affected by water markets is likely to be close to the lower bound of this range. Second, since these markets operate without any volumetric limits or other regulatory framework, there is only very little incentive for increasing water use efficiency or water saving. Although water rates vary across markets, the dominant practice of fixing them, based mainly on pumping and other operational costs, reduces their role in reflecting the scarcity of water.

Due to the size, coverage and nature of functioning, the ability of water markets to perform their economic and efficiency roles is considerably limited in the Indian context. On the other hand, there is evidence for the increasing depletion and economic loss of production due to groundwater mining. In the case of inter-sectoral water markets around peri-urban areas, where water is moved directly from irrigation to urban water supply, there can be serious livelihood issues when urban migration is low and urban-based livelihoods do not increase concurrently in the long run. Moreover, as Palanisami (2008) argues, this problem is not due to water markets per se but due to the technical and institutional conditions in which they operate. Specifically, he mentions the absence of volume-based water rights, spatial issues limiting competition and regulatory framework, including energy supply and pricing regulations and community involvement in local water withdrawal decisions. One can also add here the distorting role of land tenure that tends to link water control with landownership, especially when there are no volume-based water rights. Similarly, the absence of spacing out of wells and depth regulations also leads to the crowding of wells in agriculturally productive regions. The successful cases of water markets in countries such as the US, Australia and Chile are provided to underline the importance of supporting institutions such as volumetric allocation, water rights and water regulations to protect equity and environment.

Water Rights

Against a detailed conceptual and legal analysis of water rights within a new institutional economics framework, Narain (2008) evaluates the potential and prospects for its utility and applicability as an option for managing irrigation demand. For water rights to be effective and enduring as an institutional system for managing water, in general, and irrigation, in particular, he suggests the necessity of converting the abstract notion into an operationally applicable practical tool with a clear delineation and quantification of the volume of water. This is not going to be easy in view of the understandable legal, technical, institutional, and political challenges. But, at the same time, there are also considerable potentials for creating a volume-based water rights system as there are growing compulsions from the emerging water demand-supply realities and the attendant water-based conflicts at various levels. The arguments also make it clear that the costs and difficulties involved in establishing a water rights system can be more than offset by the potential, but definite, long-term benefits for the society. Considering the existing legal and institutional potentials and the emerging realities on the resource and technology sides, the development of water rights system will not be as difficult or costly as it is made out to be in current public discourse. In fact, water rights systems of various forms are already in operation both at the macro and micro levels in India.

Based on the review of the literature, legal and policy documents and field-level perspective of water rights, Narain (2008) concludes that while there is a clear need and basis for establishing water rights systems it will, however, be unrealistic to contemplate a single form of water rights systems applicable to all contexts. Diverse forms of water rights are needed to suit the location and context-specific realities, though there are common principles of equity, legal pluralism and negotiation. Besides the lease-based water rights issued by government in the Gangetic deltaic regions and the macro-level rights implicit in sectoral priorities, there are also semi-legal and informal rights linked to land such as the groundwater rights—based on the legal principle of easement, and canal water rights—based on the location-related principle of fixed-tenure (Saleth 2007). But, the most important ones, which are socially recognized, locally managed, and operating on a larger scale, especially in the northwestern and eastern states are the water rights based on time (as in *warabandi* system) and on volume (as in *Shejpali* system).[4] Narain (2008) provides field evidence for their role in facilitating negotiation, water allocation and use efficiency.

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[4] Notably, both the time and volume-based water rights are linked to farm size, as they are determined in proportion to land owned or operated. But, there are instances such as the *Pani Panchayat* system, where even landless persons also have a water share, which they can sell. In this case, the shares are based not on land but on family size (see Saleth 1996)

Although the semi-formal and locally managed water rights systems have an effect on water allocation and use efficiency, their impacts are not that large to perceptibly influence water demand. Obviously, this is mainly due to the absence or ineffectiveness of supportive institutions, particularly the absence of legal and institutional mechanisms for monitoring, sanction and enforcement at the top, and technical and organizational arrangements to facilitate a more accurate and responsive water allocations based on time, volume or both. In view of this institutional and technical vacuum, there is neither sufficient incentive for efficient use nor adequate compensation for water saving. Unless this serious gap is addressed quickly, these water rights, though helpful in water allocation, cannot be effective in demand management. For performing this economic role, these local water rights systems should be structures within a 'public trust framework,' where the user groups, officials, and stakeholders at different levels of the system could work together within a framework of regional, sectoral and tributary and outlet level water quota system (see Saleth 2007). The transaction costs of creating this framework are obviously high because it entails tremendous information, technical and organizational demand as well as an extraordinary level of bureaucratic and political commitment. Yet, the demand management impacts of water rights systems cannot be ensured without this framework.

Energy Regulations

Energy regulations, covering both the price and supply of electricity and diesel for irrigation purposes, are relevant for influencing water use mostly in groundwater regions, though they are also relevant even in canal areas involving lift irrigation. Malik (2008) evaluates the potential ability and actual impact of these regulations on demand management using an extensive but in-depth review of available literature and empirical evidence. The evaluation suggests that the efficacy of energy regulation as a tool for demand management depends on their intrinsic nature and enforcement as well as a number of related farm and region-specific factors such as well ownership and depth, farm size, cropping pattern, groundwater marketing possibilities and the groundwater hydrogeology itself. Energy regulations involving relatively higher and metered or use-based tariff will be more effective in controlling water withdrawals as compared to the ones based on fixed and flat rates. Similarly, regardless of the rates, direct supply regulations involving rationed and fixed hours of supply will be more effective, provided farmers do not have multiple wells, resort to illegal use of power with phase converters, or substitute or complement electric and diesel power. It is critical to consider the scope for bypassing supply regulations, monitoring and enforcement mechanisms, particularly with local involvement as well as a coordinated regulation of electric and diesel pricing and supply.

There are limits within which energy pricing can be increased, and such limits are set by the economic theory and political feasibility. While the efficient use of energy and water will require the tariff to reflect the opportunity cost or, at least, the cost of alternative energy sources, political considerations lead to tariffs that not even fully reflect the production costs. Therefore, in order to achieve the financial goals in the energy sector and the efficiency goals both in the energy and water sectors, there is an urgent need for a major change in the tariff level and structure, especially in the irrigation sector. Citing other studies (e.g., Saleth 1997; Bhatia 2007), Malik (2008) argues that for energy regulations to be effective in affecting water withdrawals, the tariff level and structure need to reflect the value of marginal productivity of energy, discriminate crops, consumption levels and locations, and be accompanied by supply rationing. But, changes in the power tariff level and structure, though critical, are not sufficient given the critical roles played by institutional and technical conditions involved not only in the transmission and distribution of energy for agricultural uses, but also in determining the access to groundwater itself.

Energy regulations do have the potential to influence water withdrawal and irrigation demand and also to improve the efficiency and financial viability of the energy sector itself. But, these roles cannot be expected to be automatic under the current conditions of tariff level and structure, bureaucratic management and unregulated groundwater access conditions. There is a need for major reforms both in power and water sectors. Malik (2008) outlines some key components of these reforms. First, considering the practical limits to which power rates can be raised and also the difficulties for them to effectively influence water withdrawal directly, it is reasonable to use them mainly to achieve the financial goals. Second, the policy of metered rates varying with consumption and crops has to be combined with supply regulations so as to directly influence water withdrawal. Third, the successful experiences in China and US and also in the piloted experiment in Gujarat suggest that the state electricity boards have to bulk distribute power to local organizations such as a panchayat (an elected governance body at the village level) and rural electricity cooperatives for them to retail power among users and collect charges. Finally, besides these changes related to the power sector, there are also changes needed in the water sector, especially the strict enforcement of spacing and depth regulations as well as the whole host of institutional and technical aspects related to establishment of legally sanctioned but locally enforced and managed volumetric water rights. When these conditions are created, energy regulations can be a powerful tool within an overall strategy of irrigation demand management.

Water Saving Technologies

The water saving technologies cover not only the methods related to water application (drip, sprinkler and micro-irrigation) but also those related to crop choice and farming practices. Unlike other demand management options, this option has a direct and immediate effect on water consumption and irrigation demand. Having reviewed the available evidence on the extent and impact of water saving technologies, Narayanamoorthy (2008) shows that these technologies can raise water use efficiency to the level of 60% (sprinkler) and 90% (drip) in irrigation. Besides the obvious savings in water that may depend on the extent the saved water is available for use elsewhere, these irrigation methods also provide additional savings in terms of energy and labor costs. Empirical studies in India establish that these irrigation technologies save 48 to 67% of water, 44 to 67% of energy costs, and 29 to 60% of labor costs. Overall, private benefit-cost ratio, which depends on the value of water productivity and the underlying role of crop prices, is impressive, ranging from 1.41 for coconut to 13.35 for crops such as grapes. In view of these economic and productivity benefits, these technologies remain highly viable in a range of crops from sugarcane, banana and grapes to even field crops such as wheat and bajra (Narayanamoorthy 1997; Kumar et al. 2004). Since these technologies are scale-neutral, they are also beneficial to farmers even with less than one hectare (Narayanamoorthy 2006). Notably, much more than the private benefits are the social benefits in terms of water savings and input use efficiency (see Dhawan 2000).

Unfortunately, despite the enormous scope and the impressive performance in terms of both private and social benefits, the spread of water application technologies is rather slow and their application is largely confined to a few states and crops. For instance, the total area under drip irrigation is not more than 500,000 to 600,000 ha. Over 85% of this area is also confined to the groundwater-dependent hard-rock states, i.e., Maharashtra, Karnataka, Tamil Nadu and Andhra Pradesh. Although the technical and economic viability of this irrigation method is established, as many as 80 crops, more than four-fifths of the current application is restricted to vegetable and horticultural crops, including mango and citrus. Notably, coconut, banana and grape together account for approximately half the area under drip irrigation. The issue of low level of application and extent of coverage also applies equally to other water saving technologies related to the selection of water conserving crops and farm practices, such as crop spacing, use of plastics and deficit irrigation. The common reason for this low level of adoption is the absence of binding incentives, which emerge not just from the expected benefits of adoption but also from the resource-based compulsions reflecting the real scarcity value of water. Under conditions of unregulated water withdrawals, the latter never enters into the irrigation use decision of farmers.

While it is true that the water saving technologies have the most direct and immediate impacts on irrigation demand, the major problem is that these impacts are limited mainly due to the limited extent of their application and the limited environment within which they are operating at present. Narayanamoorthy (2008) elaborates, then, the policy measures needed both to expand their coverage and to improve the supportive institutional arrangements. One of the main problems with irrigation technologies such as drips and sprinklers relates to the need for high initial investment. Although state subsidy can be helpful, this is not the only factor in view of the role of other factors such as extension and the need for the involvement of the technology firms as well as other actors such as the sugar factories in the targeting and active promotion of adoption. In this respect, besides the subsidy directed to farmers, it is also necessary to extend tax relief or other incentives for the technology firms and sugar factories. Equally, if not more important, however, is the need for other direct and indirect regulation on the water resource side such as water rights and energy regulations that will reflect the scarcity value of water to the farmers. Field studies reveal that the availability of cheap canal water and unregulated groundwater supply do not provide the farmers with the much needed economic compulsion for adopting the drip irrigation technologies. At the same time, adjustments in farm price and input policies are needed to bolster water conserving crops and farming practices.

User Associations and Community Organizations

User associations as well as community organizations play a major role in water allocation and demand management in the irrigation sector. They cover both the formal ones such as water user associations (WUAs) and *panchayats* as well as the implicit and informal ones such as those in *Shejpali* and *Pani Panchayats* systems, including those promoted by NGOs and other stakeholders in rural areas. Although the general attention is focused mainly on WUAs and canal irrigation contexts, other organizations and their roles in groundwater irrigation and energy distribution are also equally important. However, a careful evaluation of the WUAs, which are created and promoted under various forms of irrigation management transfer programs in the canal regions of many states, can provide an indication of the overall status and ability of user associations and community organizations in demand management, either directly or indirectly in terms of facilitating other options. M.V. Reddy (2008) has made such an assessment based on a critical review of the available literature and field evidence on the status, problems and prospects of WUAs, particularly in the canal irrigation sector.

As in the case of other options, the two most important factors that will determine the extent of demand management impacts of user associations are their area coverage and their design and effectiveness. Despite the user participation policy being promoted since the command area development programs of the 1960s and the user associations being currently promoted actively in almost all states in India, the number of formal WUAs created so far and the extent of area under their influence remain extremely low. According to Palanisami and Paramasivam (2007), the total number of formal WUAs in the country is only about 15,000 and the area they cover is not more than about 500,000 ha. Obviously, these figures do not cover the 800 WUAs created in Rajasthan and also many informal and implicit water-related organizations involved in the *Shejpali*, *Pani Panchayats* and *warabandi* operating in parts of Maharashtra, Orissa, Punjab and Haryana. While the *warabandi* system covers most canal areas in Punjab and Haryana, there are no clear estimates for the number and area coverage of the other informal systems, especially for Maharashtra. However, according to the estimates for Orissa, there were 13,284 *Pani Panchayats* covering a total area of over 800,000 ha in 2002 (V.R. Reddy 2008). Even risking a rough estimate, the total areas under the *Shejpali* and *warabandi* systems cannot be more than 3 to 4 million ha, representing only a fraction of the total canal irrigated area in India.

Much more serious than the low area coverage are the weak design and operational effectiveness of the user associations. In view of their central institutional role, user associations and community organizations are where the whole effort to promote demand management strategy is to begin first. Unfortunately, these organizations, especially the WUAs, as they exist today, are designed more to focus on the limited roles of local maintenance, cost recovery and water distribution rather than on the broad and long-term roles of being the organizational basis for developing higher levels of economic and institutional functions. As a result, the ability of WUAs to influence real water allocation and demand management is considerably limited. This does not, however, deny their positive roles in cost recovery, system maintenance and service quality in some contexts. In this respect, it is also important to note that the current policy of Maharashtra to introduce bulk water rights at the sectoral and tributary levels and involve local user associations to retail water is likely to strengthen the kind of institutional role needed for demand management.

Similarly, one cannot also deny the effective role of informal organizations, which are well documented by M.V. Reddy (2008), V.R. Reddy (2008) and Narain (2008) in the context of different states. Although their impacts are highly location-specific and also confined only to a few regional pockets, the key for policy makers is to learn the social and resource-related incentives behind these success cases and try to replicate them in the case of formal organizations. While having democratic elections and improving farmers' participation are important, much more important and challenging are the policy and institutional aspects of creating effective incentive systems for collective action. In this respect, the creation of volumetric water rights and volume-based water pricing, for instance, can create the necessary incentives for collective action and water use efficiency. This is an interesting case of structural linkages among the demand management options, where the effectiveness of user associations depends on other institutional options such as water rights and pricing that, in turn, depends on the effectiveness of the organizational aspects.

Demand Management: Analytics of Institutions and Impacts

The central message of the review of demand management options is rather clear. Although some of the options have immediate effects and some others have the potential to influence water allocation and use, these effects are rather too meager to have an impact of the magnitude needed for generating a major change in water savings and allocation. The two central problems limiting the impacts of demand management are their limited geographic coverage and operational effectiveness. Concerted policies are also lacking in really exploiting their demand management roles. All these options are pursued as if they are separate and essentially in an institutional vacuum because the necessary supporting institutions are either missing or dysfunctional in most contexts. To see why the demand management options are effective and to know how their effectiveness and performance can be improved, we can develop an analytical framework capturing the linkages and dynamics among these options and their underlying institutional structure.

Although the demand management options appear to have important differences in terms of the nature, mechanics and the gestation period of their impacts, there are fundamentally important operational and institutional linkages among them. Operationally, these options are not independent but linked due to their mutual influences on each other. Similarly, there are also intrinsic linkages among the institutions that support each of these options. A clear understanding of these operational and institutional linkages is so vital not only for designing an integrated strategy for demand management but also for determining its effectiveness and impacts on water management and economic goals. For this purpose, we can use Figure 3 depicting the analytics as well as the institutional ecology of demand management options and their joint impact on sectoral and economic goals.

Before proceeding, it is instructive to note a few key aspects of Figure 3. First, the institutions and their linkages noted for each of the options are not exhaustive but only illustrative to highlight some of the most important and immediate ones among them. This also applies to the effects or impact pathways identified both in the sectoral and macro-economic contexts. Second, since the institutions and their linkages together form the 'institutional ecology' of demand management, Figure 3 does capture the 'institutional structure.' But, the 'institutional environment' of demand management, as defined by the joint role of hydrological, demographic, social, economic and political factors, though not a role of hydrological, demographic, social, economic and political factors, and though not explicitly specified, actually operate beneath Figure 3 and, hence, will have major effects on the entire system presented therein. From the perspective of the demand management strategy, the elements defining the institutional environment are the exogenous factors, whereas the elements forming the institutional structure are the endogenous factors.

Despite its limited coverage, Figure 3 is able to place irrigation demand management in the strategic context of water and agricultural institutions as well as in the larger context of water management and economic goals. As can be seen, there are five analytically distinct but operationally linked segments. The first segment shows the sequential linkages among demand management options, where the options that form the necessary conditions for other options and those having the most intense linkages with others are shown. The next segment captures the joint effects of these options on the irrigation sector, where the water savings effected through an improved irrigation efficiency lead to expanded irrigation with existing supply and/or increased water savings. The third segment shows the sectoral and economy-wide effects of the initial effects on the irrigation sector, which are captured through increased water transfers and higher agricultural production and productivity and converted finally into the food, livelihood, water supply and environmental benefits. The remaining two segments relate to the institutional dimension of demand management and cover respectively, the immediate institutional structure and the fundamental institutional environment. Notice that the institutional structure covers not only water-related institutions but also those related to agriculture, market and technology. Although the institutional environment is not specified in Figure 3 to avoid clutter, it plays a critical role in terms of providing the economic, resource-related and political compulsions both for the adoption of the demand management options and for the creation of their supportive institutions.

Figure 3. Demand management options: Interlinkages and institutional environment.

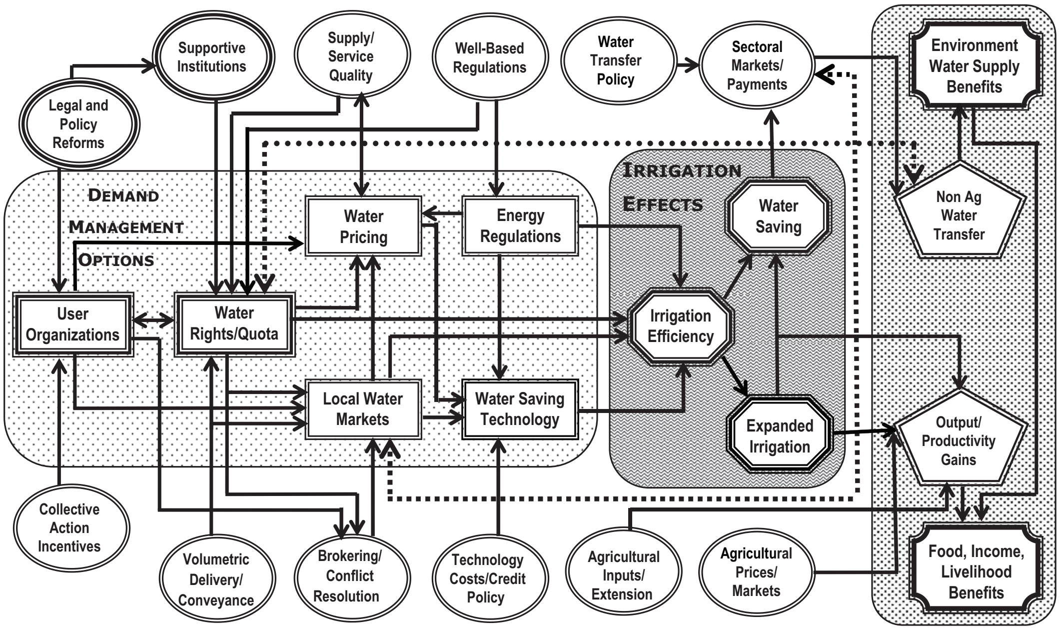

Figure 3 highlights several important points. While all the demand management options are important, the sequential linkages among them suggest that some are obviously more important than others. As noted already, this is either due to their role of being the necessary conditions for others (e.g., user associations/community organizations) or due to the extent of linkages with others (e.g., water rights/quota system). The options also differ in terms of the nature and magnitude of their impacts on irrigation efficiency and, hence, on water saving and productivity. For instance, the direct effects of user associations, water pricing and energy regulations will be neither immediate nor substantial partly because of the longer gestation period involved, and partly because its ultimate efficiency effects depend on the effects of related options and the existence and effectiveness of supportive institutions. But, water saving technologies will yield more immediate efficiency benefits, though the extent of such benefits depends on their geographic scale and crop coverage.

Obviously, the options also differ in terms of the institutional, technical and political requirements for their adoption and implementation. For instance, while it is easy to create user associations, it is more difficult to create the necessary conditions such as the incentives for collective action and the establishment of the volumetric delivery, and water quota and loss-free conveyance systems. Thus, the ability of an option to manage depends not only on how efficiently it is designed and implemented but also on how well it is aligned with other options and how effective the supportive institutional and technical conditions are. This fact highlights another strategic feature of the options. Considering the fact that institutions, including water institutions, are defined by the interactive roles of legal, policy and organizational aspects (Bromley 1989; Saleth and Dinar 2004), all options, except water saving technology, are also institutions in themselves. In this sense, the linkages among user associations, water rights, water markets, water pricing and energy regulations are actually part of the larger institutional setting of demand management. Major institutional issues are involved both in terms of the functional linkages among the options as well as in terms of the structural linkages within the supportive institutional structure.

It is also clear from Figure 3 that the institutional structure for demand management covers not only the institutions directly related to individual options but also those related to farm input and extension delivery systems, agricultural markets and price and investment policies. Responsive input and extension systems, favorable market and price conditions and well-planned investments in volumetric delivery systems and user associations are vital for the performance of demand management options. Since these sectoral and macro-economic policies affect the returns of farm-level water saving initiatives, they determine the level of economic incentives and technical scope for the adoption and extension of demand management options. Demand management options cannot operate effectively in the absence of supportive institutions. In the absence of these sectoral and macro policy measures the institutions cannot do that either. But, unfortunately, the way the demand management options are operating at present suggests that there is a clear disconnection between these options and their institutional and policy environment. Indeed this is the epicenter of all problems related to the poor performance of demand management options at present in India.

From an impact perspective, it is clear that the overall performance of a demand management strategy depends on the way it is designed and implemented. In this context, the strategy has to exploit well the functional and structural linkages among the options and also benefit from the synergies of the sectoral and macro-economic policies. For instance, the efficiency and equity benefits of water markets can be increased manyfold when such markets operate with a volumetric water rights system and are supported by effective user associations. There are also second-round institutions that can emerge through the interface among water rights, water markets and local organizations. They relate not only to the conflict-resolution roles of user associations and community-based organizations but also to the water brokering and water-delivery-related technical activities of other private agencies that are expected to thrive under mature institutional conditions. Likewise, water pricing policy can be more effective, not only in cost recovery but also in influencing water use, if it is combined with volumetric delivery, use-based allocation structures and improved system performance and service quality. Similar results can be expected also with other options, when they are aligned with other options and supported well with relevant institutional and technical conditions.

The ultimate impact of demand management can be measured in terms of the nature and scale of water savings obtained within the irrigation sector. Even when water savings are substantial, the social impact can still be low, unless the saved water is properly reallocated either within agriculture or to other sectors. The economic and welfare impacts of such reallocation can be enhanced with additional but higher-level institutional and policy aspects such as sectoral water markets and agricultural input and price policies. Thus, the final impact of demand management options within irrigation depends not only on the scale and gestation period of their sectoral impacts but also on the facilitative roles of macro-level institutional and policy aspects. Besides the issues of scale and gestation period, there is also another major issue related to the inevitability of vast uncertainties both in the full implementation and in the expected benefits of demand management options.

Towards a Demand Management Strategy

The overview of the current status and performance of the demand management options, particularly in light of the analytics of the institutional ecology and impact of demand management presented in Figure 3 makes it clear what the missing elements in the current policy in this respect are. To be real, a concerted policy for demand management in irrigation is conspicuous by its absence both at the national and state levels. Instead, what is being witnessed is a casual and ad hoc constellation of several uncoordinated efforts in promoting the demand management options. In most cases, these options are pursued lesser for their demand management objectives than for their other goals such as cost recovery and management decentralization. Even here, the policy focus is confined only to a few options such as pricing, user associations and energy regulations and, to a limited extent, water saving technologies. Although several policy documents and legal provisions clearly imply a water rights system, there are no explicit government policies either as to its formal existence or to its implementation, except for the recognition of the need for volumetric allocation and consumption-based water pricing. This is also true for water markets, though their existence and operation across the country are well documented. Considering the critical importance of water rights and water markets for their direct effects on demand management and their indirect effects in strengthening other demand management options, it is important that they are formally recognized and treated as the central components of a demand management strategy.

As we contrast the present status of demand management policy and the ideal demand management approach evident in Figure 3, we can identify several key points useful for the design and implementation of a well-coordinated and more effective demand management strategy. The functions, linkages and the institutional character of the demand management options clearly underline the need for the strategy to treat these options as an interrelated configuration functioning within an institutional environment, characterized by the overall legal, policy and organizational factors. Since the changing economic, technological and resource conditions will tend to alter the political and institutional prospects for demand management, it is important to align the policy for it to benefit from the potential synergies from the institutional environment as well. Given such an overall character and thrust of the strategy, the next step is to create technical conditions and strengthen the institutions—both formal and informal ones. The technical conditions include, for instance, the modernization of the water delivery system, introduction of volumetric allocation and installation of water and energy meters. Similarly, the institutional conditions will include, among others, the public trust framework for the joint management of users, officials, state, and communities, the creation of a separate but an embedded structure of sectoral, regional, and user level water rights within the overall supply limits at the respective levels, conflict resolution mechanisms and incentives for collective action.

The institutional and policy requirements for demand management identified above are varied and wide ranging. Considering their extent and coverage, what is needed is nothing short of some fundamental changes in the existing institutional arrangements built around the supply-oriented paradigm of water governance. This fact clearly underlines the logical link between the implementation of the demand management strategy and the necessity of broad water-sector reforms. Indeed, demand management forms the spearhead around which water-sector reforms are to be planned and implemented. While the strategic and institutional logic of designing a demand-managed strategy in itself as part of a larger program of water sector reforms is clear, its implementation is certainly not easy and quick. But, neither the stupendous nature of the task nor the heavy economic and political costs involved in transacting such a change in the current context can be a source for alarm or complacency.

There are well-tested reform, design and implementation principles that can assist policymakers in overcoming the technical, financial and political economy constraints and, thereby, effectively negotiating the demand management strategy and the institutional reforms. The reform, design and implementation principles are simple yet powerful when used carefully within a well-planned program and time frame. These principles relate to the prioritization, sequencing and packaging of institutional and technical components based on impact, costs and feasibility considerations. Besides these design-related principles, there are also principles related to implementation, which cover strategic aspects such as timing, coverage and scale. As can be seen, these principles essentially try to exploit the basic features of institutions such as path dependency, functional linkages and institutional ecology, in addition to the inherent synergies and feedback that institutions receive from the larger physical, socioeconomic and political environment. The theoretical rationale and the institutional basis for these principles are explained by Saleth and Dinar (2004, 2005), and how they have been applied in the practical context of reforms in selected countries and regions are discussed by Saleth and Dinar (2006). Here, we can briefly discuss how these design and implementation principles can be used for the planning and implementation of the demand management strategy and its underlying institutional reforms with minimum transaction costs and maximum effectiveness.

As can be seen in Figure 3, there are sequential linkages among the demand management options as well as among the institutions. For instance, we have seen user associations remain as the basis for the operation of water rights, water markets and water pricing (and also for energy regulations). Similarly, water rights are critical for the effective functioning of water markets and could also provide the incentives for the application of water saving technologies and improve the effectiveness of even energy regulations. Clearly, since the user associations are the foundation for the emergence and operation of other institutions and do not involve much political opposition, they should receive top priority from the long-term perspective. But, in the short term, the promotion of water saving technologies with the immediate and direct impact should receive priority. Since the establishment of a water rights system involves major legal, technical and political challenges, the focus here should be in creating some of the basic conditions for its emergence, such as the modernization of the water delivery systems and introduction of a volumetric allocation. Along with their roles in facilitating the eventual introduction of a water rights system, these conditions will also have direct roles in improving the effectiveness of water pricing. Besides these ways of sequencing and prioritizing demand management options and their institutional components, there are also instances for packaging programs such as the system modernization to be combined with management transfer and improved supply reliability and service quality to be accompanied by higher water rates.

Since the design principles involving sequencing, prioritizing and packaging work on the sequential linkages and path-dependent nature of institutions, they help reduce the transaction costs of creating each of the subsequent institutions. Also, in view of the institutional ecology principle, when a critical set of institutions are put in place, other institutions or new roles for existing institutions can develop on their own. For instance, when volumetric allocation is introduced, it would be possible to negotiate limits for water withdrawals, which can eventually lead to the emergence of water quota systems. Similarly, when water rights are in place, real water markets centered on established water entitlements can emerge. With these emergent institutions, the roles of user associations will also expand considerably to include new functions such as monitoring and enforcement, a forum for negotiation and conflict resolution and brokering and facilitation of water markets. More importantly, all these institutional changes will tend to expand the application of demand management options and reinforce their effectiveness and impacts on water allocation and use. The main point to note here is the importance of identifying the key institutional and technical elements that will form the core components of reforms. This can be done with an understanding of the technical needs, operational linkages, financial costs and feasibility criteria, using a framework similar to the one in Figure 3.

While the design principles do affect implementation, the principles related to the timing, coverage and scale have a more strategic role. This is because they work on the synergies and feedback emerging from a larger environment within which the institutional structure is operating. These synergies and feedbacks can relate both to exogenous factors such as macro-economic crises, energy shortage, droughts and floods, political change and the influence of external funding agencies and to endogenous factors such as water scarcity, status of water finance and the physical conditions of water infrastructure. Seizing these opportunities appropriately, with proper timing is critical for the success and effectiveness of reform programs. Beside the anticipation and choice of the right time, the issue of time is also significant for another important but least appreciated reason. This relates to the selection of a suitable time frame for the execution of the demand management strategy and its institutional program. Since institutional change is only incremental and slow, a longer time frame involving, say, a 10-year period is to be considered. But, within this frame, time-dated reform initiatives with clear prioritization and financial allocations can be planned for sequential implementation. The issue of scale and coverage is mainly determined by financial and technical considerations. Although there are economies of scale in undertaking demand management reforms, this policy cannot be ideal in all contexts. Ideally, it would be useful to prioritize regions and areas where different demand management options and initiatives can be introduced. For instance, while water pricing policy and energy regulations can cover a larger area, it is useful to target scarcity areas so that these options can have a significant impact.

Concluding Remarks

The urgent need and compelling rationale for demand management in the irrigation sector can hardly be overstated, especially given the binding limits for supply expansion and the persisting levels of water use inefficiency. But, unfortunately, the present status and performance of individual demand management options leave much to be desired. While there are cases of limited success in efficiency improvements, especially in the case of demand management options such as user associations, water saving technologies and water markets, they are too few to have the magnitude of efficiency and water saving benefits that are needed at present. The overview of the performance of demand management options clearly shows how their extent and effectiveness are constrained by several institutional, technical and financial factors. But, a much more serious issue is the absence of a clearly articulated policy for water demand management both at the national and state levels, even though demand management has been very much in policy discourse for a long period. Even though there are policies for promoting user associations, water saving technologies, water pricing or energy regulations, they are implemented mostly in an ad hoc or partial manner.

The formulation of a demand management policy cannot be considered as a ceremonial need because it is the policy statement that provides the basis for the much-needed financial and political commitments for implementing demand management programs. Such a policy can also represent a formal shift from the outdated supply-oriented paradigm that has governed water development, allocation, use and management so far. Since an effective demand management strategy can both expand irrigation and also release water for other productive uses even at the current level of water use, it is logical to divert, at least part of the investments that are currently going into new supply development. Although some of the demand management initiatives have a long gestation period, this may not be as high as that associated with new water development projects, especially considering the delay caused by environmental problems and interstate water conflicts. Besides the direct returns from demand management investments, there are also long-term effects since demand management options and their institutions can enhance the efficiency and sustainability benefits not only in the irrigation sector but also in the water economy as a whole.

An analytical framework similar to the one presented in Figure 3 can help understand the analytics and dynamics of impacts of a demand management strategy. As we have shown, this framework provides considerable insights on the operational linkages among the options and functional linkages in the underlying institutions. A demand management strategy delineated in the light of these linkages, formulated within a more realistic time frame and implemented with the design and implementation principles can be more practical and effective in achieving the efficiency and water saving goals within the irrigation sector. Broadly, this strategy involves a sequencing, prioritization and packaging of demand management tools and also their institutions. Similarly, the principles involving the issues of timing, scale and coverage can also be used for planning the implementation of the demand management strategy. While implementing the strategy, areas and regions can also be prioritized in terms of their relative feasibility and also the available financial resources for investment on demand management. The central idea is to achieve immediate efficiency benefits as much as possible while gradually paving the way for institutional and technical foundation for similar benefits in the long term. The approach of gradual, sequential and consistent implementation of demand management strategy within a well-planned time frame is likely to neutralize possible resistance, minimize transaction costs and maximize long-term impacts.

While India has to go a long way in formulating and implementing a demand management strategy as discussed here, one cannot be that pessimistic given the recent trends of institutional changes observed in India (see Saleth 2004). Although the observed changes are slow, partial and inadequate, their direction and thrust are on the desired lines. Several states have raised the water rates and there has also been a gradual and steady improvement in cost recovery. The issues of volumetric allocation and water entitlements have also been receiving increasing public and policy attention in recent years. In Maharashtra, the policy of volumetric allocation on a bulk basis has been introduced. Many policies that were once considered as anathema, such as water markets, privatization and de-bureaucratization are already a reality in India's water sector. There are also constant pressures from factors both endogenous and exogenous to the water sector (e.g., the physical limits for supply augmentation, food security compulsions, water supply challenges and energy issues) for further changes in water policies and institutions. Since the path dependency properties of institutions will ensure that it is costlier to return to the status quo than to continue to proceed with the reform path, the institutional environment is going to favor the formulation and implementation of the demand management strategy sooner than later. Obviously, there is a clear policy demand for more research-based studies for exploring still further the design and implementation properties of irrigation demand management strategy.

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Water Productivity Improvements in Indian Agriculture: Potentials, Constraints and Prospects

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Introduction

India is still an agrarian country although the structure of the economy is gradually changing. Industrialization and urbanization set off in the 1990s resulted in a greater contribution from the manufacturing and service sectors to the national economic output. Today, the agriculture sector contributes to only 17% of the gross domestic product (GDP), yet nearly 70% of the country's population live in rural areas and the majority of this proportion depends on agriculture-related economic activities for their livelihoods. Projections show that it would take another five decades before the population starts stabilizing (Visaria and Visaria 1995). Hence, sustaining agricultural production, particularly the production of food grains in tune with population growth and changing consumption patterns, is an important task, which is not only essential for feeding the growing population for a large country like India but also important for supporting livelihoods and reducing the poverty of India's large rural population[2] (Chaturvedi 2000). Moreover, water demand in nonagricultural sectors, including that for the environment, is increasing and many regions in the country are facing severe water stress (Amarasinghe et al. 2005, 2008a). Thus, efforts to manage water efficiently in the agriculture sector and produce more crop and value per drop are gaining momentum now more than ever before.

Agriculture continues to account for a major share of the water demand in India (Amarasinghe et al. 2008a). The southwest monsoon provides a major part of India's annual

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[2] Several studies in the past have indicated that agricultural growth, especially growth in food grain production positively impacted on reducing rural poverty (Hazzle and Haggblade 1991; Rao 1994; Ghosh 1996; Desai and Namboodri 1998). Rural poverty has correlated with relative food prices, which is affected by fluctuations in food supply (Ravallion 1998; Dev and Ajit 1998).

rainfall, and the quantum varies widely across space (GoI 1999). In most places, growing crops require an artificial provision of water during the non-monsoonal seasons and in some places even during the monsoon. In fact, only one-third of the agricultural production in the country comes from rain-fed areas, which account for two-thirds of the croplands. As per official projections, a major share of the future growth in India's agricultural production would have to come from increasing cropping intensity, and bringing rain-fed areas under irrigated production, rather than expanding the net cultivated area (GoI 2002), all of which would require irrigation water.[2]

The extent of net additional irrigation at the aggregate level would depend heavily on three aspects. The first two aspects—the extent of growth needed in agricultural production, particularly production of food grains; and the extent to which we can increase the productivity of water use in agriculture are well recognized and researched. However, the third aspect, how and where those improvements in water productivity (WP) are going to occur are less recognized.

But, the last aspect on WP improvements is extremely important. It is a false notion that raising the production of a particular crop by a certain degree, by increasing WP, would compensate for the increase in future water demand for raising the production of a particular crop by the same degree. Several situations explain this false notion.

1. A region can get all its production from rain-fed crops. In such a case, it is quite possible that the productivity improvement comes from an increase in yield of crops in a rain-fed area, through supplementary irrigation. WP gains through supplementary irrigation would only help us take some of the rain-fed areas out of cultivation, thereby freeing some of the agricultural land for other uses. However, most of the water used up by rain-fed crops, i.e., soil moisture, in these rain-fed lands cannot be reallocated to irrigate crops or for any other use. Thus, it will not reduce the need for diverted water.

2. The sum of the extent of water resource augmentation for irrigation in different regions could be more than the required net increase in irrigation water supply at the aggregate level. For instance, a region could have great scope for WP improvement through reduction in consumptive use of water for irrigation. But these regions may not have much additional land, such as Punjab or Haryana. Such gains in WP will not reduce the need for additional water supply in another region that has additional arable land to produce food. Nevertheless, it would only free up some of the water resources in the first region for reallocating to the environment or to another sector of use.

3. If WP (kg/evapotranspiration) improvements can come from supplementary irrigation of rain-fed crops in one region, such as certain parts of central India or in the Godavari basin in Peninsular India, which has low levels of water resources development, then it would still require a lot of additional water. This additional water, however, can be at the expense of water availability of another region with fully developed water resources for intensive irrigation. The latter, by reducing its irrigated area or improving the productivity in its region by shifting to water-efficient non-food crops, parts with its water for the benefit of the former region.

4. If reduced consumptive water use in irrigated crop production can improve WP, then this would lower the need for increased irrigation only if additional land is available for

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[2] However, this does not mean that growth in production from rain-fed areas is not possible without large irrigation infrastructure. Sharma et al. (2009) showed that small supplementary irrigation in critical periods of water stress can significantly increase productivity in rain-fed lands.

cultivation in the same area to achieve a greater crop output with the saved quantum of water. If the improvement comes from an increased use of fertilizers in certain regions, which also brings about crop yield improvements, then this would mean there would be a reduced need for augmenting irrigation.

All of the above-mentioned hypothetical situations actually exist in India. So, in the ultimate analysis, it would appear that the benefit of WP improvement cannot be fully translated into an equivalent reduction in the requirement for developing additional water resources, although significant reductions could still be possible. However, the outcomes of WP improvement would be multiple. It increases the streamflows in some areas; reduces pressure on groundwater in some other areas; boosts productivity and production freeing up rain-fed land in yet some other areas with a consequent increase in streamflows from the river catchments owing to change in land use hydrology. All these are important for the country. So improving WP in agriculture is an important component of a water-sector perspective plan. A water-perspective plan for water resources for India should indicate:

- How the demand for water will increase in different sectors, including the environment, and in different regions.
- How much of the additional demand for water can be managed through improvements in WP in different competitive sectors of water use in different regions.
- What kind of interventions would be required for improving productivity of water use and at what scale (supplementary irrigation, controlled water allocation, micro-irrigation, conservation technologies, etc.).
- How much of this gets translated into real reduction in irrigation water demands in every region where it matters, or does it actually increase water demand in some regions.
- What should be the increase in utilizable water supplies in different regions. And what should be the aggregate increase in water supplies, after considering interregional reallocation of the freed-up resource.

This book explores the potential interventions for WP improvement in Indian agriculture, the scale of adoption of these interventions and their potential impacts on future agricultural water demand.

The papers in this book are the results of various research activities conducted in Phase III of the project on ‘Strategic Analyses of National River Linking Project’ (NRLP) of India (CPWF 2005). Phase I and II of the NRLP project assessed ‘India’s Water Futures: Scenarios and Issues’ (Amarasinghe et al. 2009) and ‘Social, Hydrological and Environmental Cost and Benefits of the River Linking Project’ (Amarasinghe and Sharma 2008), respectively. Phase III studies explored various options to interlinking of rivers, which can contribute to an alternative water-sector perspective plan for India. As part of this, Saleth (2009) explored the potential and prospects for, and constraints in, promoting demand management strategies in the Indian irrigation sector. The chapters in this book assess potential and prospects for, and constraints in, promoting WP improvements in the Indian agriculture sector. They provide fresh empirical analyses based on primary data across India on crop inputs and outputs and also district-level secondary data on crop production, crop yields and agro-meteorology. They cover both rain-fed areas and irrigated areas. In addition to field crops, the analysis also included dairying under composite farming systems.

This book discusses various complex considerations involved in analyzing WP in agriculture in India that goes beyond the conventional ‘crop per drop’ paradigm. It further examines how integration of these considerations in assessing WP provides us with new opportunities or sometimes induces constraints in the traditionally known approaches for enhancing WP in agriculture. It discusses various improvement measures of WP in both rain-fed and irrigated areas, not only at the field level but also at the farm level and regional/ basin level. It also specifies the regions where these measures would work, by using empirical evidence from various locations in India. But, while doing this, it also analyzes the macro-level constraints induced by physical, technological and infrastructure-related, socioeconomic, and institutional and policy environments, which can limit the scale of adoption of these interventions. Finally, it discusses the scale of WP improvements in rain-fed and irrigated agriculture, and qualitatively assesses their implications on future agricultural water demand. The book has seven papers, including this one.

The second paper by Amarasinghe and Sharma analyzes WP in food grains (kg/ET) in India to assess the potential scale of improvement. It uses district-level data on crop yields, production, and cropped area under both rain-fed and irrigated food grain crops, along with data on crop evapotranspiration estimated using agro-meteorological data. It analyzes the role of the key determinants of overall WP of food grain crops at the regional level, such as cropping pattern, irrigation pattern, and crop consumptive use (ET), in driving WP improvements in food crops. The paper identifies three key interventions for improvement in physical productivity of water in food grain production in India, and the number of districts to which each one of them is applicable.

The third paper by Kumar, Trivedi and Singh analyzes the impact of quality and reliability of irrigation on crop WP, by comparing field level WP of major crops under well irrigation and canal irrigation and under conjunctive use of well water and canal water. This study first derives quantitative criteria for assessing the quality and reliability of irrigation water. The assessment is based on primary data on farming systems collected from farmers in two agro-climatic regions of the Bist Doab area in Punjab, India, which use different modes of irrigation. The paper evaluates the quality and reliability of water in canal irrigation, well irrigation and conjunctive use in quantitative terms; compares WP (both physical and economic) under different supply sources; analyzes the impact of the quality and reliability of irrigation on crop WP and cropping pattern and identifies the factors responsible for the differential productivity.

The fourth paper by Alok Sikka presents the analysis of WP in various multiple use systems that support fisheries, tree production and dairying within the farm along with paddy, which are generally considered as a single use system. The study argues that WP assessment on the basis of the returns from crops alone and the amount of water applied and used would lead to an underestimation of agricultural WP. This paper discusses the findings of research studies undertaken to assess WP in some specially designed experimental systems of multiple uses in eastern India. The various multiple water use systems include, 1) secondary reservoir-cum-fish ponds in the tube well command in Patna; 2) fish-trench-cum-raised bed for fish-horticulture, and rice-fish farming in seasonally waterlogged areas in Patna under the traditional rice-wheat system; 3) on-dyke horticulture and fish-prawn-poultry system, and subsurface water harvesting with fish culture in coastal Orissa; and 4) rainwater harvesting ponds for fish-prawn farming with fruits and vegetables on the pond bunds in rain-fed areas of Ranchi in Jharkhand in the central plateau. This paper also discusses the impacts of introducing different production systems such as fish, prawn, horticulture and poultry in rice-wheat system on agricultural WP. Furthermore, it includes an analysis of impact of conservation technologies, viz., zero tillage-bed planting and drip irrigation on crop WP in wheat and banana, respectively.

The fifth paper by Singh and Kumar examines the factors determining water intensity of dairy farming other than climate. For this, it synthesizes empirical data available from two locations in India, viz., northern Gujarat, western Punjab, both representing semiarid climatic conditions. But, the two regions are markedly different in terms of the nature of dairy farming. The first one is commercial dairying, which is intensive and depends heavily on irrigated fodder crops. In the second case, dairy heavily depends on by-products from crops. This paper presents the data on feed, fodder and water inputs in dairy production, expenditure on livestock keeping, milk yields, and WP in dairying for different categories of livestock. This study shows that dairy production is highly water-intensive when it is commercial, and is still water-intensive but more efficient when it is part of mixed farming. It also shows that the nature of trade-offs involved in maximizing agricultural WP under the two situations are different. Furthermore, an empirical analysis from Kerala, which is a subhumid area, demonstrates the impact of climatic change on the water intensity of dairy production. It shows that milk production is highly water-efficient in regions like Kerala, but the lack of availability of sufficient arable land becomes a constraint to intensive milk production.

The sixth paper by Kumar and van Dam discusses the various determinants for analyzing WP in Indian agriculture that are markedly different from those used in the west. It also identifies some major gaps in WP research and the key drivers of change in WP. The main arguments are 1) in developing economies like India the objective of WP research should also be to maximize net return per unit of water and aggregate returns for the farmer, rather than merely enhancing 'crop per drop;' 2) the determinant for analyzing the impact of efficient irrigation technologies on the basin-level WP and water saving should be the consumed fraction (CF) rather than evapotranspiration; 3) in closed basins, determinants for analyzing basin-level WP improvement through water harvesting and conservation should be incremental economic returns and opportunity costs; 4) at the field level, the reliability of irrigation water and changing water allocation could be the key drivers of change in WP, whereas at the farm level, changes in the crop mix and farming system could be key drivers of change. In composite farming systems, measures to enhance WP should be based on farm-level analyses. At the regional level, concerns of food security, employment and market risks can reduce the ability to significantly improve WP in agriculture.

The seventh paper by Kumar further discusses potential, prospects and constraints for improving agricultural WP in India. It first discusses the various considerations in analyzing WP in India. Some of them are: 'scale of analyses,' i.e., field to farm to region or field to system to river basins; objective of WP assessment; food security; and regional economic growth and environmental sustainability. It then discusses how integration of these considerations in analyzing WP changes the way we assess agricultural WP improvements. While new windows of opportunity for WP improvement are created, it also creates some new limits. For instance, taking the basin as a unit for WP enhancement measures leaves us with the opportunity for improving WP using the climatic advantage, as within the same basin, climate often varies remarkably. It then summarizes various interventions for WP enhancement in rain-fed and irrigated agriculture, which are discussed in various papers. This is followed by a discussion of various macro-constraints in enhancing agricultural WP in rain-fed agriculture that are social, economic and financial in nature. In the case of irrigated agriculture, the constraints are physical, technological and infrastructural, institutional, and market- and policy-related. Finally, the scale at which various WP improvement measures could be adopted in India and their potential impact on future growth in agricultural water demand is assessed.

Why Is WP Improvement in Agriculture Crucial for India?

Many of India's agriculturally prosperous regions are water-scarce, where the natural endowment of water is poor (Amarasinghe et al. 2005), while the demand for water in agriculture alone far exceeds the utilizable renewable water resources (Kumar et al. 2008b). The common features of these regions are excessive withdrawal of groundwater and excessive diversion of water from rivers, which cause environmental water stress. Agriculture is the major user of water in these regions, particularly for irrigated crops, with very high per capita water use in irrigation (Kumar et al. 2008c). Agriculture is in direct conflict with other sectors of the water economy and environment. The scope for augmenting the utilizable water resources in these regions is extremely limited. While there are many regions in India where water resources are abundant, most of them have limited potential for increasing agricultural production due to the limitations imposed by land and ecological constraints. So, improving WP in agriculture, wherever possible, holds the key not only to sustaining agricultural production and rural livelihoods but also to making more water available for other sectors including the environment.

The world over, agriculture has very low water use efficiency when compared to manufacturing (Xie et al. 1993; Turner et al. 2004), and the situation is no different in India. Agriculture continues to be the largest user of diverted water in the country (Amarasinghe et al. 2008a; GOI 1999). Moreover, productivity of water use in India is very low for major crops in terms of the amount of biomass produced per unit of water depleted in crop production. The reasons are many.

First, India has some of the lowest yields in cereal crops viz., wheat and rice (Amarasinghe and Sharma, paper 2, this book). They consume large quantities of irrigation water in aggregate terms (Amarasinghe et al. 2005), compared to what is biologically possible to consume by these crops for a given variety, in the given temperature and solar radiation The factors responsible for this could be lack of irrigation, deficit irrigation or excessive irrigation, or lack of soil-nutrient management through optimal dosage of fertilizers and micro-nutrients, poor on-farm water management or farm management. Furthermore, what is biologically possible may not be economically viable or in other words optimal. It is particularly true in areas where the soils are degraded with poor micro- and macro-nutrients, which demands application of huge quantities of nutrients to achieve the maximum yield. The latter increases the input costs, reducing the net income. Also, many crops are grown in regions where the climate is not fully favorable for realizing good yields.

Second, irrigation water use efficiencies are poor in India (GOI 1999) due to inefficient irrigation practices or unfavorable soil conditions. Flood irrigation, level border irrigation and, to an extent, furrow irrigation are generally practiced by Indian farmers for agricultural crops. The adoption of water-efficient irrigation technologies has been by and large very poor to date. One example of an unfavorable soil condition is the practice of growing irrigated paddy in light soils. Excessive deep percolation would require frequent watering of the crop to keep the ponding of water in the field. Another important issue is the adoption of short-duration food crops, which are inherently inefficient in water use in terms of amount of grain yield per unit of water consumed (ET), but survive on rains, in vast regions of India, owing to lack of irrigation facilities.

Improving WP in agriculture can bring about many positive outcomes. While in some regions WP improvement would result in increased crop production with no increase in consumptive use of water, in some others it would result in reduced use of surface water or groundwater draft. Both would protect the environment. On the other hand, there are certain regions in India where yields are very poor as the crops are purely rain-fed in spite of having a sufficient amount of unutilized water resources. Augmenting water resources and increasing irrigation in such regions can result in enhanced yield and income returns, as well as water productivity improvements. Hence, such strategies have the potential to reduce poverty in these regions.

Opportunities and Constraints for WP Improvements

As various papers included in this book show, there are several opportunities for improving the WP of crops. They include

- providing irrigation to crops that are currently rain-fed so as to meet the full crop evapotranspirative demand for realizing the yield potential (Amarasinghe and Sharma, paper 2, this book);
- adopting long-duration food crops, which have higher water use efficiency, and replacing short-duration ones, which have low efficiency, again possible through the availability of irrigation water (Amarasinghe and Sharma, paper 2, this book);
- growing certain crops in regions where their yields are higher due to climatic advantages (high solar radiation and temperature for instance), better soil nutrient regimes or lower ET demand (high humidity for instance)—(Abdulleev and Molden 2004; Loomis and Connor 1996);
- improving quality and reliability of irrigation water (Kumar, Trivedi and Singh, paper 3, this book; Palanisami et al. 2008); managing irrigation for certain crops, which could mean controlling allocation or increasing allocation to the said crops (Kumar and van Dam, paper 6, this book);
- adopting high-yielding varieties without increasing the crop consumptive use (Amarasinghe and Sharma, paper 2, this book);
- providing optimal dosage of nutrients, such as artificial fertilizier, and improving farming systems with changes in crop and livestock compositions (Singh and Kumar, paper 5; Kumar and van Dam, paper 6, this book).

But, there are constraints to improving WP for irrigated crops induced by land availability (Amarasinghe and Sharma, paper 2, this book; Singh and Kumar, paper 5, this book), food security concerning regional economic growth (Kumar and van Dam, paper 6, this book) and existing institutional and policy frameworks. For instance, in many situations, improvement in WP in kg/ET or Rs/ET does not guarantee better returns for the farmers due to inefficient pricing of water and electricity, and absence of well-defined property rights in water

(Kumar and van Dam, paper 6, this book; Kumar et al. 2008a). Cereals such as wheat and paddy, growing of which is important for meeting national food-security needs, have much lower water use efficiency, as compared to cash crops such as cotton, castor and groundnut (Kumar and van Dam, Paper 6, this book). In the case of rain-fed crops, many communities lack the knowledge and wherewithal to adopt technologies and practices to improve WP in agriculture. Finances required for investing in water harvesting systems for supplementary irrigation for rain-fed crops, and its economic viability are critical issues (Kumar, Paper 7, this book).

In a nutshell, while there seem to be great opportunities for improving WP in agriculture, to what extent these can be achieved in real practice depends on the scale at which the above-mentioned constraints operate. Also, as we have discussed earlier, to what extent the improvement in WP can be leveraged to reduce the demand for additional storage, for India depends on the source of WP improvement. It is quite clear that though we can avert the need for new development of water resources for irrigation to a great extent through WP improvements, some interregional transfers of water saved from the committed releases in certain regions, resulting from improved WP of crops in these regions, might still be required.

Institutional and Policy Measures for WP Improvements

The policy constraints concern the pricing of water used in canal irrigation and electricity used in well irrigation, whereas the institutional constraint comes from the lack of well-defined water rights for both surface water (Kumar and Singh 2001) and groundwater (Kumar 2005). Both these factors leave minimum incentives for farmers to invest in measures for improving crop WP as such measures do not lead to improved income in most situations (Zekri 2008; Kumar et al. 2008a). The electricity supplied for groundwater pumping needs to be metered and charged on a pro-rata basis in regions where well irrigation is intensive. The State of Gujarat, one of the most agriculturally prosperous states in the country, has already started doing this, where nearly 40% of the agricultural connections are now metered and farmers pay electricity charges on the basis of actual consumption.

The other measures that can be taken up in the short term are improving the quality of irrigation water supplies from canal systems, including provision for intermediate storage systems like the ‘diggies’ in Rajasthan (Amarasinghe et al. 2008b); improving quality of power supply in agriculture in regions that have intensive groundwater irrigation, with longer-duration supplies along with an improved tariff structure; improving electricity infrastructure in rural areas of eastern India; and provision of targeted subsidies for micro-irrigation systems in regions where their use results in major social benefits. This would help maximize the scale for adoption of micro-irrigation systems, and potential impacts in terms of WP improvements. On the other hand, investment in irrigation infrastructure for supplemental or full irrigation would significantly enhance crop yields in many areas and WP in some rain-fed areas. This would be a medium-term measure.

Future Research

The concept of WP improvements in agriculture is relatively new. The amount of scientific assessment of WP available from research studies is heavily skewed in terms of geographical coverage, the scale of analysis, crop types, and the determinants used in assessments. These assessments mainly covered wheat, paddy and maize among food grain crops; and cotton among cash crops. Most of the assessments, which are for developed countries in the west, look at biomass output per unit of water depleted or applied and are done at the field scale looking at individual crops (Zwart and Bastiaanssen 2004; Kumar and van Dam 2008). There are quite a few unknowns in the field of WP, which can hinder making the right kind of policy decisions for managing water demand in agriculture that does not cause any undesirable consequences for the farming communities and society. Next, we discuss a few of these unknowns that require further research.

1. The possible trade-off between improving WP of individual crops and the entire farm level needs to be better understood under different socioeconomic environments. For instance, while shift from irrigated paddy and wheat to water-efficient fruits and vegetables might help achieve higher crop WP, it might affect the output of milk from the farm, thereby affecting the WP of the farming system as dairying under 'mixed farming' conditions was found to be highly water productive (Kumar and van Dam 2008). The unknown here is the overall value of WP in dairying under different farming conditions (Rs/m^3). Also, the risk involved in cultivation of some of the vegetables and fruits, is very high when compared to dairy farming and paddy cultivation. This is one reason why many farmers prefer to adopt the wheat-paddy system, which involves the least agronomical and market risk.
2. There is very little useful research available that can be used to estimate the WP (both physical and economic) of many perennial fruit crops. The most crucial piece of information needed here is the amount of water consumed annually by the crop (ET) with increase in age of the plant, the change in yield over the years, and the irrigation water requirements in different years under different agro-climatic conditions. The issue of water consumption by tree crops is quite complex. While many trees consume large quantities of water, depending on the foliage, a good portion of this water comes from deep soil strata. In deep water table areas, the moisture held up in the 'vadoze zone' (hygroscopic water), which is not available for recharge or consumption by smaller plants, would provide this water. Hence, the impact of the trees on the actual water balance needs better understanding.
3. The possible trade-offs between improving agricultural WP of an individual farm and an entire region needs more assessment. For instance, the introduction of certain cash crops might help raise the field- and farm-level WP, thereby benefiting the farmers who adopt it. But, extensive adoption of these crops by a large number of farmers in a region might result in increased market risk, resulting from over-production and price crash. The research question is, what should be the optimum level of adoption of such crops in different regions to save water as well as to sustain farm economy?
4. The general perception is that micro-irrigation (MI) systems help raise the WP of crops and that there is sufficient analytical work now available, to show that the extent of real water saving possible with MI is a function of the soil, climate, geohydrology, and type of technology used (Kumar et al. 2008a,). But, unfortunately, change in the quantity of water applied after adoption of the technology is often perceived as reduction in water use. When researchers proceed with their analyses of physical and economic impacts of MI systems using such assumptions, it leads to false policy prescriptions. Most of the available research on water saving and WP impacts of MI systems is based on the

estimation of change in applied water. What is important is to know how the consumptive fraction changes under different climates, soils, water table conditions, and how it affects different crops.

5. The WP and income improvements that are possible through the conversion of single use systems into multiple use systems under different multiple use combinations require better understanding. This is a very crucial area for research because there appears to be several limitations to maximizing WP and income returns through the conventional route in many regions due to physical, technological, financial and climatic constraints. For instance, in the wetlands of cold/hot and subhumid areas, paddy is a dominant crop. It is difficult to shift from paddy to high-valued crops here. The reasons are many. Paddy is not amenable to micro-irrigation systems. Wetlands are not suitable for growing fruits and vegetables. At the same time, if the same land is also used for growing fish or shrimp, the returns could be enhanced significantly. Also, growing tree crops might enhance the returns. The biggest research challenge would be proper accounting of the water used in farms that helps assess the marginal productivity of various farming systems such as tree crops, field crops, duck-rearing and fishery.

Conclusions

With increasing water scarcities, WP enhancement in agriculture is not only relevant, but also very crucial in meeting future water demands of the agriculture and other sectors. There are several constraints in enhancing WP in agriculture. But, there are several opportunities too. However, the constraints can be reduced and the opportunities enhanced through appropriate institutional and policy interventions. WP improvement would definitely reduce the need for future investments in the new development of water resources in some regions. But, due to regional variations of water supply and use, the extent of reduction in demand for additional water for meeting future needs will not be the same as the scale of aggregate savings of water achieved by enhancing WP. However, it might result in more water being available for environmental uses or reallocation to other sectors in some regions wich were earlier used for growing crops.

The other outcomes of WP improvement are: reduced poverty due to rise in farm income in the agriculturally backward regions; reduced environmental stresses caused by excessive pumping of groundwater or diversion of water from streams/rivers; and better availability of water from basins for allocation to environmental uses or freeing up of a large amount of cultivated land under rain-fed production, resulting in increased streamflow generation from catchments. They all help meet the future water demand of different water use sectors. In fact, WP improvements in agriculture can be a major component in a water-sector perspective plan in India.

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Climatic Change and Groundwater: India’s Opportunities for Mitigation and Adaptation

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Abstract

For millennia, India has been using surface storages and gravity flow to irrigate its crops. During the last 40 years, however, India has witnessed a decline in gravity flow irrigation and the rise of a booming “water-scavenging” irrigation economy through millions of small, private tube wells. For India, groundwater has become at once critical and threatened. Climatic change will act as a force-multiplier; it will enhance the criticality of groundwater for drought-proofing agriculture and simultaneously multiply the threat to the resource. Groundwater pumping with electricity and diesel also accounts for an estimated 16-25 million tonnes of carbon emission, 4-6% of the country’s total emission. From the point of view of climatic change, India’s groundwater hot spots are western and Peninsular India. These are critical for mitigation of, and adaptation to, climatic change. To achieve both, India needs to make a transition from surface storages to “managed aquifer storage” as the comerstone of its water strategy with proactive demand and supply-side management components. In doing this, India needs to learn intelligently from the experience of countries like Australia and the USA that have long experience in managed aquifer recharge.

Evolution of Indian Irrigation

Irrigation has always been central to life and society in the plains of South Asia, i.e., India, Pakistan, lower Nepal, Bangladesh and Sri Lanka. According to Alfred Deakin, a three-time Australian Prime Minister and an irrigation enthusiast of the early 20th century who toured British India in 1890, the region had 12 million hectares (ha) of irrigated land compared with 3 million ha in the USA, 2 million ha in Egypt, 1.5 million ha in Italy and a few hundred thousand ha each in Ceylon (Sri Lanka, since 1972), France, Spain and Victoria (Australia) (The Age 1891). Although Egypt and Sri Lanka are better known as hydraulic civilizations of yore, a century ago British India was the world’s irrigation champion. This is not surprising. In

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[1] The author acknowledges support for preparing this paper from the IWMI-Tata Water Policy Program and the Challenge Program Project (CP 48) on “Strategic Analyses of India’s National River Linking Project.”

a normal year, India receives 4,000 km^3 of rainfall precipitation, large by any standard; but a large part of it falls in eastern India. Moreover, almost all of it is received within 100 hours of torrential downpour, making storage and irrigation critical for the survival of agrarian societies. Considering that parts of India, chiefly the Indo-Gangetic Basin, were densely populated and intensively cultivated more than even 2,000 years ago suggests that water-managed agriculture has been the bedrock of civilization in this part of the world. However, the technology of water-managed agriculture has undergone profound changes over the millennia. Three distinct eras of irrigation evolution can be identified according to the technology used and the institutions it has spawned:

Era of Adaptive Irrigation

From time immemorial to the early 1800s, farming communities adapted their agrarian lives to the hydrology of river basins. There are records of numerous, often gigantic, irrigation systems constructed by kings and managed by specialized bureaucracies. This induced historians like Karl Wittfogel (1957) to famously claim that irrigation drove state-formation in oriental societies like India's; and the administrative requirements of managing large, state-run systems were at the root of the rise of despotic authority in these societies during a period when many countries in Europe had well-entrenched republican institutions. However, the sum total of the evidence suggests that, at least in today's South Asia, farming communities and local overlords, rather than the monolithic state, were key irrigation players in Mughal India and earlier. Diverting and managing monsoonal flood water to support riverine agriculture was the dominant mode in northern India and Pakistan with sandy alluvial aquifers; and using them to fill up countless small reservoirs was the standard procedure in hard-rock parts of Peninsular India (Shah 2008a).

Era of Canal Construction

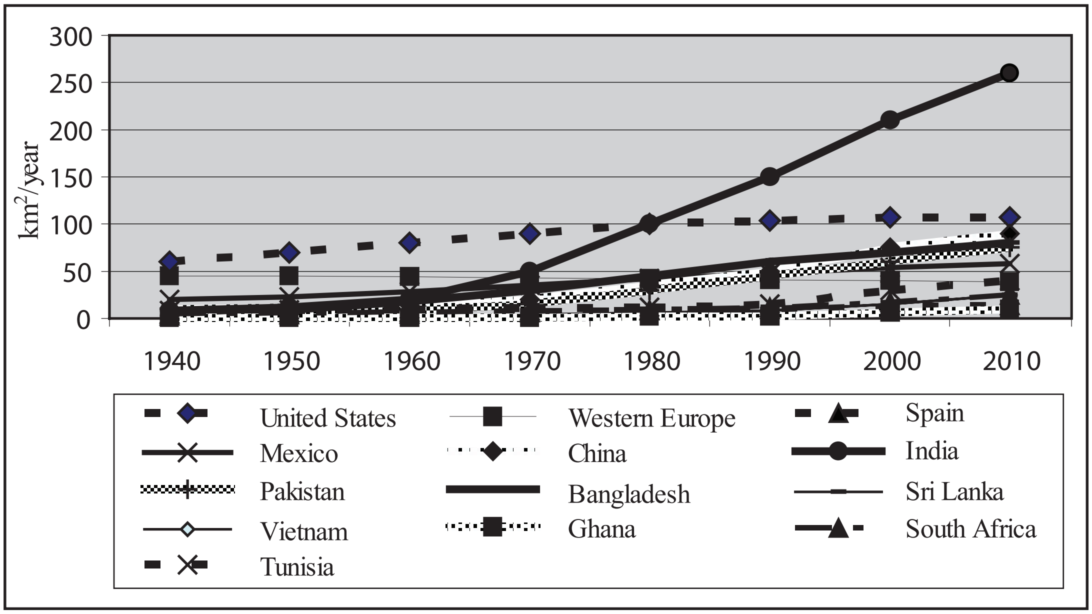
Around 1810, the British East India Company began changing this adaptive irrigation regime by undertaking gigantic projects that reconfigured river basins. The Indus canals transformed northwestern (British) India from a pastoral region to an intensively cultivated terrain. Large canal projects were also undertaken in the south of India. In ambitious irrigation projects, the colonial rulers combined the "interests of charity and the interests of commerce" (Whitcombe 2005). The state and centralized irrigation bureaucracies replaced village communities and local landlords as key players in the new regime. Civil engineering began dominating water planning, construction and management, and continued to do so even after India gained independence and remains predominant today. The colonial era left India and Pakistan with some of the world's largest gravity flow irrigation systems, complete with a highly centralized, bureaucratic irrigation management regime.

Era of Atomistic Irrigation

The colonial irrigation strategy however created pockets of agrarian prosperity in canal commands which even as recently as 2,000 encompassed no more than 15% of India's farming areas. However, India has experienced an explosion in agricultural population since 1960;

and the land:man ratio declined from over 0.4 ha/person in 1900 to less than 0.1 ha/person in 2000. The peasants around the country felt the need to secure a means of irrigation that could permit intensification and diversification of land use. At this time the availability of small mechanical pumps and boring rigs provided a technological breakthrough. Beginning in 1970, this combination of circumstances catalyzed a groundwater revolution all over South Asia. This was a wholly new phenomenon that the water establishment was unfamiliar with. Northwestern India had seen some well-irrigation even during colonial times; however, irrigation of field crops with groundwater was wholly new to humid eastern India and hard-rock Peninsular India. In India, the number of irrigation wells equipped with diesel or electric pumps increased from 150,000 in 1950 to nearly 19 million by 2000. Around 1960, India was a relatively minor user of groundwater in agriculture compared to USA and Spain; by 2000, the country had emerged as the global champion in groundwater irrigation, pumping around 220-230 billion m^3/year, i.e., over twice the amount the USA had pumped as the chart in Figure 1 shows.

Figure 1. Growth in agricultural groundwater use in selected countries during 1940-2010.



Source: Author's estimates based on various sources.

The policy making regarding India's water is yet to fully factor in this epochal transformation in the way its farmers water their crops; and governments keep investing billions of dollars on new surface water reservoirs and canal networks even as the existing ones have begun falling into disuse. Evidence gathered around 2007 suggests that since 1990, central and state governments in India have invested over US$20 billion in building new, and rehabilitating existing, surface irrigation systems; however, the net area served by surface structures, small and large, has actually *declined* by over 3 million ha (Shah 2008a; Thakkar and Chandra 2007). In contrast, net area served by groundwater has been steadily rising. Small farmers looking for opportunities to intensify and diversify their agriculture need year-round on-demand irrigation more frequently. Altough tanks and canal systems are unable to meet this need groundwater wells are able to do so. Groundwater wells are also a better insurance against a drought than tanks and canal systems. As a result, since 1990, Indian irrigation has been transformed from a centrally-managed surface irrigation regime to an atomistically managed water-scavenging irrigation regime involving tens of millions of pump owners who divert surface water and groundwater at will. Even as groundwater irrigation helped South Asia's smallholders survive, myriad environmental impacts have followed as a result of unmanaged overexploitation of the resource. The key consequences of intensification of groundwater use in agriculture in different parts of the subcontinent are given in Table 1.

Table 1. Key consequences of intensification of groundwater use in agriculture in different parts of the subcontinet.

Hydrogeological settings		Socioeconomic and management challenges			
		Resource-depletion	Optimizing conjunctive use	Secondary salinization	Natural groundwater quality concerns
A. Major alluvial plains	A.1. Arid	●●	●●	●●●	●
	A.2. Humid	●	●●●		●●
B. Coastal plains		●●	●	●●●	●
C. Intermontane valleys		●	●●	●	●
D. Hard-rock areas		●●●	●	●	●●●

Note: The number of dots suggests the scale and severity of a challenge.

Groundwater Management Challenges in Different Areas of India

This transformation and the socioecological threats it implied necessitated a totally new policy response from governments and water planners. The meteoric rise of the atomistic groundwater economy demanded bold new thinking and a resource allocation strategy to evolve a groundwater management regime with practical supply- and demand-side strategies. However, steeped in colonial irrigation thinking, Indian water planners still keep spending billions of dollars on the canal irrigation technology that farmers throughout India have been roundly rejecting. If canals are ending up as groundwater recharge structures by default, the question is whether it would not be more effective to do so by design.

Even as India's groundwater irrigation economy remains pretty much ungoverned, climatic change will present new challenges and uncertainties, and demand new responses from the region's water planners. The rise of the booming groundwater economy and the decline in surface irrigation necessitate a totally new understanding of the operating system of India's water economy and how best it can mitigate as well as adapt to the hydro-climatic change.

India's Hydro-Climatic Future

Climatic change is expected to significantly alter India's hydro-climatic regime over the twenty-first century. It is widely agreed that the Indo-Gangetic Basin will experience increased water availability from snowmelt up to around 2030 but face gradual reductions thereafter. Parts of the Indo-Gangetic Basin may also receive less rain than in the past; but the rest of India is likely to benefit from greater precipitation. According to IPCC (2001), most of the Indian land mass below the Ganges Plain is likely to experience a 0.5-1 degree rise in average temperature during 2020-2029 and a 3.5-4.5 degree rise in 2090-2099. Many parts of Peninsular India, especially Western Ghats will experience a 5-10% increase in total precipitation (IPCC 2001);[2] however, this increase will be accompanied by greater temporal variability. Throughout the subcontinent, it is expected that 'very wet days' will contribute more and more to total precipitation suggesting that more of India's precipitation may be received in fewer than 100 hours of hailstorms—and half in less than 30 hours— as has been the case during recent decades. This would mean higher precipitation intensity and a larger number of dry days in a year.[3] Increased frequency of extremely wet rainy seasons (Gosain and Rao 2007) will also mean increased runoff. According to Milly et al. (2008), compared to 1900-1970, most of India will experience a 5-20% increase in annual runoff during 2041-60. All in all, India should expect to receive more of its water through rain than through snow, get used to snowmelt occurring faster and earlier, cope with less soil moisture in summer and higher crop ET demand as a consequence.

For Indian agriculture, hydro-climatic change will mean the following:

- *Kharif* (monsoon from May to September) season crops will experience heightened risk of floods as well as droughts.
- *Rabi* (from October to April) and especially summer crops will experience enhanced ET needing larger, more frequent irrigation.
- Surface water storages—large and small—will benefit from increased runoff but will also suffer increased evaporation from large open surfaces of reservoirs and open canal networks as a result of higher mean temperature.
- Irrigating the same area through canals will necessitate larger reservoir storage; more frequent droughts will also mean greater need for multiyear reservoir storage capacity of which India has very little at present.

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[2] In some ways, this may reflect a continuation of some past trends. Based on analyses of rainfall data over the 1872-2005 period, Basishtha et al. (2007) identified a secular decline in rainfall in North India barring Punjab, Haryana, West Rajasthan, Saurashtra and an increase in rainfall in southern India.

[3] By analyzing a daily rainfall data set, Goswami et al. (2006) have shown a rising trend in the frequency of heavy rain events and a significant decrease in the frequency of moderate events over central India from 1951 to 2000.

From these and other points of view, managing groundwater storage will acquire greater significance for India than ever before. However, besides groundwater demand, climatic change is expected to affect groundwater supply too in direct and myriad ways.

Impact of Climatic Change Impacts on Groundwater

To the extent that climatic change results in spatial and temporal changes in precipitation, it will significantly influence natural recharge. Moreover, since a good deal of natural recharge occurs in areas with vegetative cover, such as forests, changing ET rates resulting from rising temperatures may reduce infiltration rates from natural precipitation thus reducing recharge. Recharge responds strongly to the temporal pattern of precipitation as well as to soil cover and soil properties. In the African context, Carter (2007) has argued that replacing natural vegetation by crops can increase natural recharge by up to a factor of 10. If climatic change results in changes in natural vegetation in forests or savanna, these too may influence natural recharge; however, the direction of net effect will depend upon the pattern of changes in the vegetative cover. Simulation models developed by Australian scientists have shown that changes in temperatures and rainfall influence growth rates and leaf size of plants that affect groundwater recharge. The direction of change is conditioned by the context: in some areas, the vegetation response to climatic change would cause the average recharge to decrease, but in other areas, recharge to groundwater would more than double. Changing river flows in response to changing mean precipitation and its variability, rising sea levels, and changing temperatures will all influence natural recharge rates (Kundzewich and Doll 2007).[4]

We know little about how exactly rainfall patterns will change; but increased temporal variability seems guaranteed. This will mean intense and large rainfall events in short monsoons followed by long dry spells. All evidence we have suggests that groundwater recharge through natural infiltration occurs only beyond a threshold level of precipitation; however, it also suggests not only that runoff increases with precipitation but the runoff coefficient (i.e., runoff/precipitation) itself increases with increased rainfall intensity (or precipitation per rainfall event). Higher variability in precipitation may thus negatively impact natural recharge in general. The net impact on a given location will depend upon whether it experiences greater or smaller total precipitation as a result of climatic change.

The Indo-Gangetic aquifer system has been getting heavy recharge from the Himalayan snowmelt. As snowmelt-based runoff increases during the coming decades, their contribution to potential recharge may increase; however, a great deal of this may end up as “rejected recharge” and enhance river flows and intensify the flood proneness of eastern India and Bangladesh. As the snowmelt-based runoff begins declining, one should expect decline in runoff as well as in groundwater recharge in this vast basin.[5]

A major interplay of climatic change and groundwater will be witnessed in coastal areas. Using the records of coastal tide gauges in the north Indian Ocean for more than 40 years, Unnikrishnan and Shankar (2007) have estimated a rise in sea level between 1.06 and 1.75 mm per year, consistent with 1-2 mm per year global sea-level rise estimates of IPCC.

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[4] www.gwclim.org/presentations/plenary/kundzewicz.pdf

[5] Data monitored on the Himalayan glaciers present a confusing picture. They indicate recession of some glaciers in recent years, but the trend is not consistent across the entire mountain chain.

Rising sea levels will threaten coastal aquifers. Many of India’s coastal aquifers are already experiencing salinity ingress. This problem is particularly acute in the Saurashtra Coast in Gujarat and the Minjur aquifer in Tamil Nadu. In coastal West Bengal, Sundarban is threatened by saline intrusion overland, affecting its aquifers. The precarious balance between freshwater aquifers and seawater will come under growing stress as sea levels rise. According to the Ghyben-Herzberg relation, a 1 foot rise in sea level decreases the depth of the freshwater-seawater interface by 40 times as much (Kundzewich and Doll 2007). Coastal aquifers are thus likely to face serious threats from rise in the sea level induced by climatic change.

Some scientists suggest climatic change may alter physical characteristics of aquifers themselves.[6] Higher CO_2 concentrations in the atmosphere, they argue, may influence carbonate dissolution and promote the formation of crest that, in turn, may negatively affect infiltration properties of the topsoil. Others have argued the opposite. From experimental data, some scientists have claimed that elevated atmospheric CO_2 levels may affect plants, the vadose zone and groundwater in ways that may hasten infiltration from precipitation by up to 119% in the Mediterranean climate and up to 500% in the subtropical climate.[7]

Rethinking Storage

The response of aquifers to droughts and climatic fluctuations is much slower than that to surface storages; as a result, compared to surface storages, aquifers act as a more resilient buffer during dry spells, especially when they have large storages. This is why India has experienced explosive growth in groundwater demand during recent decades; and this is also why groundwater demand will expand further in the wake of climatic change. For millennia, groundwater wells have been the principal weapon Indian farmers have used to cope with droughts (Shah 2008a). This is evident from the fact that digging of wells has tended to peak during drought years. This trend continues even today and will likely increase with heightened hydro-climatic variability. All in all, while we can predict with confidence that climatic change will enhance the demand for groundwater in agricultural and other uses, there is no clarity on whether climatic change will enhance or reduce natural groundwater recharge in net terms under the business-as-usual (BAU) scenario.

For millennia, India has relied on building surface storages and gravity-flow irrigation to water crops. With the groundwater boom, India’s irrigation economy has been fundamentally transformed, bringing into question its age-old emphasis on surface structures. Climatic change raises new questions about continued reliance on surface storage and transport of water to agriculture, and demands that India fundamentally rethink its storage strategy. Table 2 compares four storage alternatives India faces along a dozen criteria using a ten-point scale that assigns up to five ‘↑’ signs for positives (benefits) and up to five ‘↓’ signs for the negatives (costs, disbenefits). The four alternatives compared are:

- The first, advocated by environmental and civil society groups, emphasizes numerous small decentralized storages close to the point of use and with short canals. India’s age-old

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[6] Aquifers are also of interest to researchers on climate for other reasons. Growing literature on Carbon Capture and Storage (CCS) and Geological Sequestration hints at opportunities that aquifers—especially saline and otherwise unusable—offer themselves as “carbon storehouses.” This paper, focusing on climatic change-groundwater-agriculture interaction, does not deal with these aspects.

[7] www.sciencedaily.com/releases/2007/10/071006091012.htm

traditional water harvesting structures—such as tanks in South and eastern India, *ahar-pyne* systems of southern Bihar, homestead ponds of West Bengal and North Bihar, *johads* of Rajasthan—represent this class (Choppra 2005).

- The second, emphasized by government bureaucracies, represents the dominant colonial and post-colonial strategy of creating large reservoirs at hydraulically opportune sites and transporting water through a vast network of surface canals.
- The third represents the groundwater boom India has experienced in which mostly shallow aquifer storage has been relentlessly exploited through atomistic action by millions of small farmers without any demand-side management or a systematic strategy of enhancing aquifer recharge.
- The fourth represents an option that is as yet nonexistent but can be operationalized with a paradigmatic shift in the country's water management thinking; it recognizes that groundwater demand will increase, but given India's hydrology, aquifer storage can sustain this increase with proactive demand management and a nationwide program of Managed Aquifer Recharge.

Table 2. Climatic change and water storage alternatives.

		Small surface storages	Large surface reservoirs	Aquifer storage (BAU)	Managed Aquifer storage
1	Makes water available where needed (space utility)	↑↑↑	↑↑	↑↑↑↑	↑↑↑↑↑
2	Makes water available where needed (time utility)	↑	↑↑	↑↑↑↑	↑↑↑↑↑
3	Level of water control offerd (form utility)	↑	↑↑	↑↑↑	↑↑↑↑
4	Non-beneficial evaporation from storage	↓↓↓↓	↓↓	↓	↓
5	Non-beneficial evaporation from transport	↓↓	↓↓↓	↓	↓
6	Protection against mid-monsoonal dry spell (2-8 weeks)	↑↑	↑↑↑	↑↑↑↑↑	↑↑↑↑
7	Protection against a single annual drought	↑	↑	↑↑↑	↑↑↑↑↑
8	Protection against two successive annual drought	↑	↑	↑↑	↑↑↑↑
9	Ease of storge recovery during a good monsoon	↑↑↑↑↑	↑↑↑↑	↑↑	↑↑↑
10	Social capital cost of water storge and transport and retrieval structures	↓↓	↓↓↓↓↓	↓↓	↓↓↓
11	Operation and maintenance of social costs of storage, transport and retrieval structures	↓	↓↓	↓↓↓↓↓	↓↓↓
12	Carbon footprint of agricultural water use	↓	↓↓	↓↓↓↓↓	↓↓↓

Rows 4, 5, 10, 11 and 12 in Table 2 include costs or disadvantages of different storage structures; the rest are benefits/positives. Of the benefits and costs, some, like operating costs (row 11) and quality of access (rows 1, 2 and 3) are private in nature and drive the choices of individual farmers. Others are "public" (or social) in nature; for instance, the carbon-footprint of alternative storage systems may not directly influence individual farmer decisions but they have to be factored into the national calculus.

Since the 1970s, high scores of groundwater irrigation on space, time and form utility (rows 1, 2 and 3) have driven India's groundwater boom. Also important has been the resilience of groundwater against dry spells and droughts (rows 6, 7 and 8). Surface storages have fared poorly on these counts. These benefits will become more valuable as climatic change heightens the hydrological variability. From the society's viewpoint, aquifer storage has the advantage of minimum non-beneficial evaporation (rows 4 and 5); for a mostly semiarid country, where surface reservoirs can lose 3 meters or more of their storage every year simply through pan-evaporation; this is no mean gain. The major social disadvantages of heavy dependence on groundwater are: (a) aquifers are slow to recharge; and hard rock aquifers that underlie 65% of India have limited storage; (b) while gravity flow irrigation from canals needs little or no energy, groundwater irrigation is energy-intensive; and (c) since the bulk of the energy used in pumping groundwater uses diesel or electricity generated with coal, India's transition from flow irrigation to pump irrigation has created a massive carbon footprint.

Carbon Footprint of India's Groundwater Economy

Transformation of Indian irrigation from gravity-flow to lift has made it highly energy-intensive; but the arithmetic of computing the carbon footprint of this economy is fraught with widely divergent estimates. Around 2000, Indian farmers lifted some 150 km^3 of groundwater using electric pump sets and around 80 km^3 using diesel pump sets. Lifting 1,000 m^3 of water to a height of 1 meter uses up 2.73 kWh of energy without friction losses and at peak efficiency (Nelson and Robertson 2008, personal communication). Indian electric irrigation pumps probably operate at 40% efficiency; moreover, transmission and distribution losses in delivering power to pump sets are of the order of 25% or higher. This implies that electricity actually used to lift 1,000 m^3/m in India is of the order of 9.1 kWh. If we assume that a representative electric pump lifts water to a dynamic head of 20 meters, then lifting 150 km^3 of groundwater requires 27.3 billion kWh of electricity. This estimate is highly sensitive to the assumption about the dynamic head over which a representative electric pump set lifts water. Taking a value of 40 meters yields an electricity consumption value of 55 billion kWh.

Using India's 2001 Minor Irrigation Census data on groundwater irrigated area[8] and the energy consumed in agriculture (Planning Commission 2007, annexure 2.4)[9] combined with some assumptions, Rao (2008, personal communication) estimated total electricity consumption in groundwater irrigation at 87 billion kWh. Another indirect estimate is provided from numbers circulating in the electricity industry. The total power generation in India is around 560 billion kWh; and many observers suggest that power used by irrigation pumps may be around 15% of the total generation (Planning Commission 2007), giving a total agricultural consumption of around 84 billion kWh. However, this means that either the transmission and

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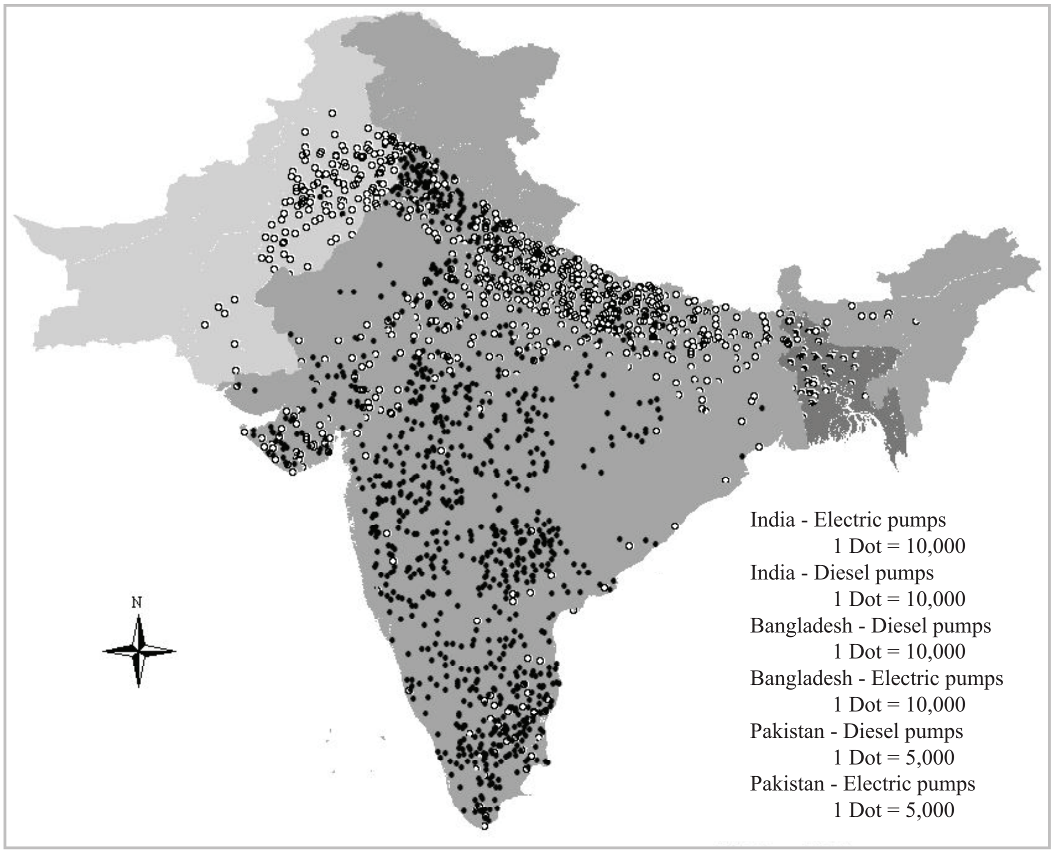
[8] wrmin.nic.in/micensus/mi3census/reports/integrated/integrated_report.htm

[9] planningcommission.nic.in/reports/genrep/rep_grndwat.pdf

distribution (T&D) losses are much higher than 25% as we assumed[10] or that the dynamic head over which a representative electric pump set in India lifts water is more like 50-60 meters rather than 20 meters that our estimate of 27.3 billion kWh is based on. The latter appears highly unlikely; the 2001 Minor Irrigation Census (Government of India 2005a, Table 6.2) found that just around 8.5% of India's villages had a static water level deeper than 50 meters; in 75% of the villages, depth to static water level was less than 15 meters. True, pumping depth can be much higher than the static water level; yet, such a huge difference is difficult to explain.

Figure 2. Distribution of electric and diesel pump sets in South Asia.



Diesel pumps are even less efficient but they lift water to a smaller head; moreover, diesel does not face the T&D losses that electricity suffers and a liter of diesel provides an equivalent of 10 kWh of energy. Some 80 km^3 of groundwater lifted by diesel pump sets uses around 4-4.5 billion liters of diesel. A paper under preparation at the IFPRI has taken the carbon intensity of electricity and diesel at 0.4062 kgC/kWh and 0.732 kgC/liter, respectively (Nelson and Robertson, 2008, personal communication). This would imply that groundwater pumping in India results in the emission of a total of some 14.38 million tonnes of C—11.09 million tonnes by electric pumps and 3.29 million tonnes by diesel pump sets. IFPRI work in progress

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[10] A study by Indian Institute of Management, Ahmedabad claims that of the "actual calories used by farmers out of 100 calories generated at the power plant are barely 2%" (IIMA: 93). This excludes the fossil energy used in mining and transporting the fuel for the thermal plants.

tentatively estimates the C-emission from groundwater irrigation to be higher at 16 million tonnes, roughly 4% of India's total C-emissions.

Two interesting aspects of the carbon footprint of India's groundwater economy are that: (a) lifting 1,000 m^3/m using electricity emits 5.5 times more C than using diesel; and diesel pumps are concentrated in eastern India with rich alluvial aquifers; (b) C-emission of groundwater irrigation is highly sensitive to the dynamic head over which groundwater is lifted because, first, higher head leads to higher energy use and C-emission; second, beyond a depth of 10-15 meters, diesel pumps become extremely inefficient forcing irrigators to switch to electricity which has a larger C-footprint anyway. Figure 2 shows that most of India's diesel pumps are concentrated in eastern India and her electric pumps, in western and Peninsular India. Table 4 presents this distribution for all of groundwater-irrigating South Asia, i.e. India, Pakistan, Bangladesh and the Nepal terai region. Indeed, as the calculations made by J. Rao in Table 4 show, 96% of India's electricity use in groundwater pumping is concentrated in 11 states of western and Pzzh eninsular India. Even amongst these, the biggest C-culprits are states like Karnataka, Tamil Nadu, Andhra Pradesh and Gujarat which have large areas under deep tube well irrigation. Deep tube wells have a huge C-footprint; according to preliminary calculations of IFPRI, India's deep tube wells irrigate only 4.1 million ha of the 31 million ha under electric pump set irrigation; but these account for nearly two-thirds of C-emission from groundwater pumping with electric pump sets.

Table 3. Geographic distribution of electric and diesel irrigation pumps in South Asia.

	Number of irrigation pumps (million)	Diesel (%)	Electric (%)
Pakistan	0.93	89.6	10.4
Bangladesh	1.18	96.7	3.3
Eastern India: Assam, West Bengal, Bihar, Orissa, Jharkhand, Uttar Pradesh, Uttarakhand, West Bengal	5.09	84.0	16.0
Western and southern India: Andhra Pradesh, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu	11.69	19.4	80.6

Sources: 1. Values for Pakistan are from Pakistan Agricultural Machinery Census 2004.
2. Values for Bangladesh are from Mandal 2006.
3. Values for Indian states are from the third Minor Irrigation Census 2000-01 (Government of India 2005a).

Table 4. Estimates of electricity consumption by pump sets in major states of India.

State	Gross area irrigated with electric pumps	Average kWh used per ha of irrigation	Total electricity used by electric pumps (gWh)
Rajasthan	3,844	1,111.8	42,74,000
Uttar Pradesh	14,010	353.4	49,51,000
Haryana	2,267	2,432.1	55,14,000
Madhya Pradesh	2,783	2,006.5	55,83,000
Punjab	5,748	1,086.2	62,43,000
Karnataka	1,285	6,997.0	89,93,000
Tamil Nadu	1,666	5,630.9	93,82,000
Maharashtra	3,311	3,193.0	1,05,72,000
Andhra Pradesh	2,294	5,863.4	1,34,48,000
Gujarat	2,713	5,293.6	1,43,61,000
Others	5,060	7,436.0	37,62,500
Total	44,981	1,934.9	8,70,31,584

Source: Rao, J., personal communication 2008.[11]

An alternative procedure for estimating C-emissions from India's groundwater economy, set out in Table 5, too draws heavily on the data provided by the Minor Irrigation Census. The Census provides numbers of different groundwater and lift irrigation structures, diesel as well as electric pumps, and gross area irrigated by each class. Several micro-level surveys suggest that deep tube wells in India operate for around 1,600 hours/year, that diesel pumps, because of high fuel cost, operate for around 600 hours, but electric pumps, subject to a flat tariff charge operate for 800-1,000 hours. Without having to estimate the energy needed to lift water from different depths, it is assumed that annual hours of operation for different structures are based on survey data. Average horse power ratings of different structures are averaged from the data provided by the Census. The T&D losses in power between generating station and well-head are assumed at 30%. This procedure (a) yields a total C-emission of 25.64 million tonnes from India's lift irrigation economy, some 60% higher than the IFPRI estimate and around 6.4% of India's total emissions; (b) shows deep tube wells to be less "dirty" than the IFPRI procedure makes them out to be; and (c) shows diesel pumps to have a much lower carbon footprint than electric pumps as the IFPRI analysis suggests.

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[11] https://login.yahoo.com/config/login_verify2?.intl=us&.src=ygrp&.done=http%3a//groups.yahoo.com%2Fgroup%2FWaterWatch%2Fmessage%2F6680 (last consulted on November 14, 2008).

Table 5. An alternative procedure for estimating C-emission from India's groundwater economy.

	Deep tube wells	Shallow tube wells: electric	Shallow tube wells: diesel	Dug wells: electric	Dug wells: diesel	Surface lift: electric	Surface lift: diesel
Number of structures (m)	0.53	3.26	4.37	6.15	1.99	0.33	0.21
Gross area irrigated (m ha)	4.09	11.61	16.06	9.99	3.23	1.22	0.78
Average horse power	9.66	6.26	6.26	4.43	4.43	5.1	5.1
Energy use/hour at well-head	7.3 kWh	4.7 kWh	1.25 (liters)	3.3 kWh	0.9 (liters)	3.83 (liters)	1
Average hours of operation/ year	1,600	900	600	900	600	600	600
Average hours/ha	207.3	252.8	163.5	554.2	369.6	162.2	162.2
T&D efficiency[12]	70%	70%		70%		70%	
Total energy used[13]	8.34 b kWh	19.7 b kWh	3.28 b	26.1 b kWh	1.07 b	1.1 b kWh	0.13 b
Total estimated emission (tonnes)[14]	3.39	8.0	2.4	10.6	0.78	0.45	0.1
Emission/ha (C-tonnes)	0.83	0.69	0.15	1.06	0.24	0.37	0.13

Discussions on climatic change and groundwater are at a very early stage in India. However, preliminary studies show massive scope for reducing the C-footprint of India's groundwater economy. Using data for Haryana and Andhra Pradesh, Shukla et al. (2003) built a quantitative model to estimate the marginal impacts of a host of factors on greenhouse gas (GHG) emissions from pumping. Some of the conclusions of the study were: (a) every meter decline in pumping water levels increases GHG emissions by 4.37% in Haryana and 6% in Andhra Pradesh; (b) the elasticity of GHG emissions with respect to percent of area under groundwater-irrigation is 2.2; and through the 1990s, groundwater irrigated area in these two states increased at a compound annual growth rate of 3%/year, resulting in an increase in GHG emission at 6.6%/year; (c) every 1% increase in the share of diesel pumps to total pumps reduces GHG emissions by 0.3%; and (d) the elasticity of GHG emissions with respect to irrigation efficiency is high at 2.1. The most important determinant of the C-footprint of India's pump irrigation economy is the dynamic head over which farmers lift water to irrigate crops.

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[12] Transmission and distribution efficiency in conveying power between generating station and well-head

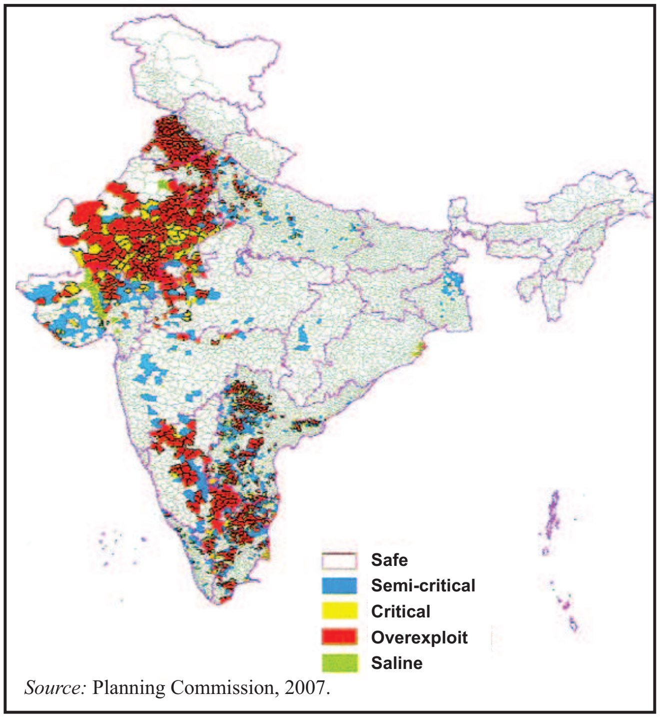
[13] Computed by multiplying rows 5, 4 and 1

[14] C-emission per kWh of electricity is assumed at 0.4062 kg and per liter of diesel at 0.732 kg (Nelson and Robertson 2008).

Groundwater Recharge for Adaptation and Mitigation

From the viewpoint of climatic change, India's groundwater hot spots are concentrated in arid and semiarid areas of western and Peninsular India, especially in Punjab, Rajasthan, Maharashtra, Karnataka, Gujarat, Andhra Pradesh and Tamil Nadu, as is evident from the map of groundwater overexploited areas (Figure 3). Continued overexploitation of groundwater has severely curtailed the resilience of their aquifers and their ability to stabilize farming livelihoods in the face of heightened hydro-climatic variability. Groundwater here is pumped from great and increasing depths mostly using coal-based electricity; hence, these are also the regions which account for an overwhelmingly large proportion of GHG emissions from groundwater pumping. Accepting the present dependence of agriculture on groundwater as a fait accompli should lead policymakers to evolve a strategy of "proactive management of aquifer storage" as the central plank of India's water strategy in the years to come. This strategy needs to incorporate effective means to manage agricultural water demand as well as to enhance natural groundwater recharge through large-scale "Managed Aquifer Recharge" investments. Without demand- and supply-side management of the pump irrigation economies, groundwater levels in most Indian aquifers display behavior caricatured in Figure 4a. In the initial years, water level fluctuations before and after the monsoon get amplified; however, as pre-monsoonal water levels drop considerably below the vadose zone, natural recharge rates decline and the pumping head increases rapidly. With proactive demand and supply-side management, the situation desired is caricatured in Figure 4b. With groundwater development, fluctuations will amplify; however, as long as post-monsoonal water levels bounce back to predevelopment levels with managed aquifer recharge, a steady state can be approached, albeit with rising average pumping head.

Figure 3. Groundwater-stressed areas of India.



Source: Planning Commission, 2007.

Figure 4a. Groundwater development and water level decline without managed aquifer recharge.

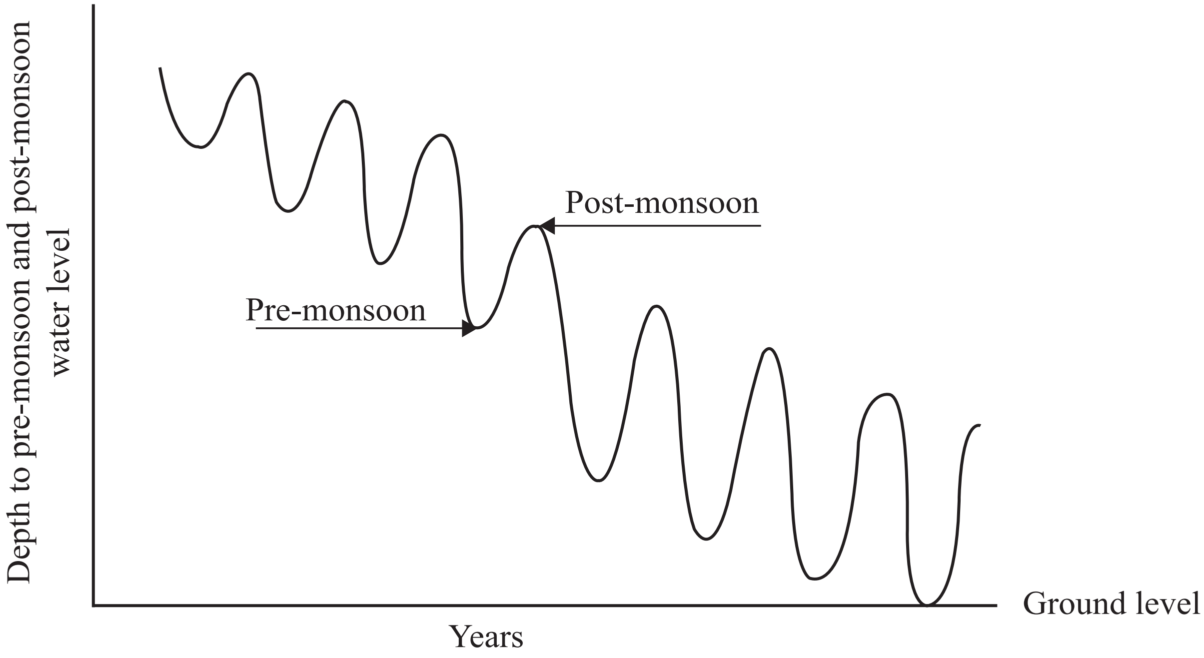
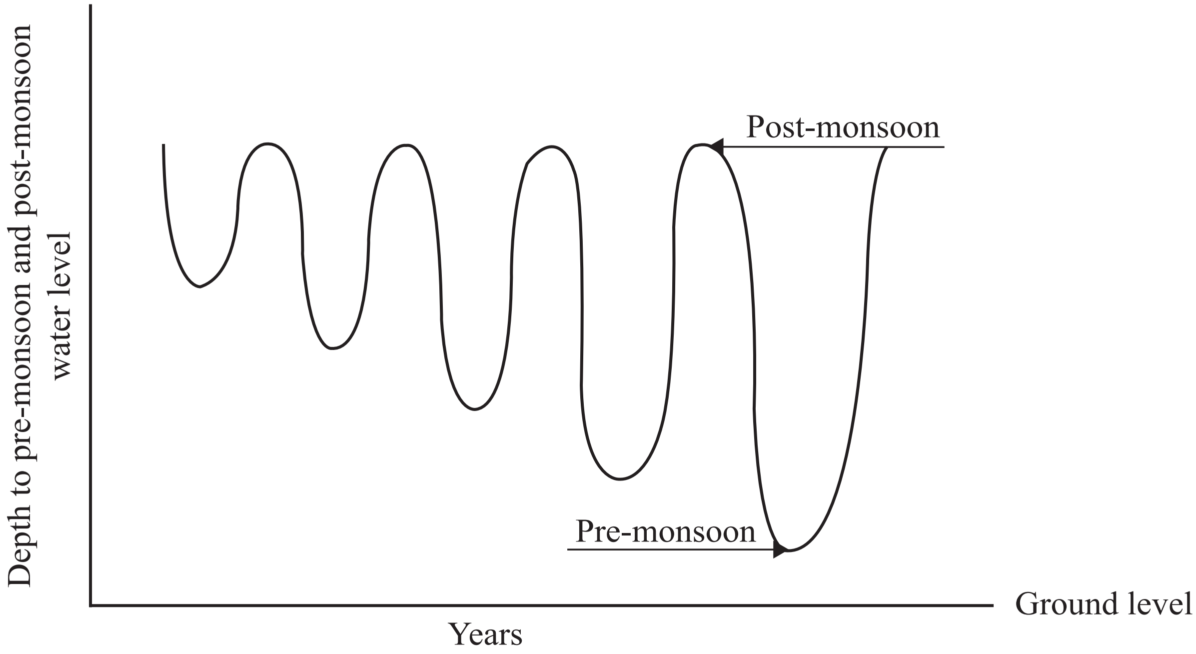


Figure 4b. Groundwater development and water-level behavior with intensive program of managed aquifer recharge.



India has witnessed growing discussions on how best to manage the runaway expansion in demand for agricultural groundwater. Laws and administrative regulations-such as licensing-have been extensively discussed and even tried; however, the key challenge is in enforcing these on several tens of millions of widely dispersed pumpers in a vast countryside (Planning Commission 2007). Many observers have also suggested pricing of groundwater but the administrative and logistical challenges of doing these are even more formidable. Groundwater irrigation is the mainstay of India's small farmers and the rural poor; therefore, governments and political leaders are reluctant to adopt a heavy-handed approach to curtail groundwater demand (Shah 2008b). The political objective therefore is to seek environmental goals in ways that do not hit the poor. For over a decade, IWMI has argued that, in the short run, the only effective and practical approach of groundwater demand management in India is through rationing of agricultural power supply (Shah et al. 2004). During recent years, Gujarat in western India has experimented with this approach with considerable success. The government of this state invested US-$ 250 million in rewiring rural Gujarat's electricity infrastructure under *Jyotirgram* scheme to separate feeders supplying power to farm-consumers from those that take power to nonfarm rural consumers. The electricity company has been rationing farm power supply, forcing farmers to use power and groundwater more efficiently, and curtailing aggregate groundwater withdrawals significantly (Shah et al. 2008).

On the supply side, the key transition India needs to make is from surface-storage to aquifer storage. Intensive groundwater development has created problems, but also opportunities. Until the 1960s, when India withdrew 10-20 km^3 of groundwater, it experienced very little natural recharge to its predevelopment aquifer-storage; most runoff was rejected recharge. Today, India's Central Groundwater Board estimates that some 10% of India's annual precipitation of 4,000 km^3 ends up as natural recharge without any significant effort on anybody's part. If a fraction of the resources and energies that India expends on building new surface reservoirs and canal systems is directed to promoting large-scale groundwater recharge in her groundwater hot spot areas of western and Peninsular India, the country can greatly reduce its GHG emissions from pumping and also restore the resilience of its aquifers to protect agriculture from heightened hydro-climatic variability (Shah 2008b).

Groundwater recharge therefore needs to become the new mantra for India's water policy. In this respect too, India needs to evolve strategies and technologies that suit its unique conditions. In hard-rock areas of India, farmers have built over 9 million large open wells at their own cost. These can be up to 8 meters in diameter and 60-70 meters in depth. Many have also invested in several—sometimes dozens of—horizontal and vertical bores inside them to enhance their connectivity with nearby water-bearing fractures. So far, these wells are used only for withdrawing water; but these can as well be used as excellent recharge structures if the sediment-load of surplus flood-water during monsoons could be reduced using simple filtering and desilting technologies. However, Indian thinking on groundwater recharge is shaped by the experiences and technologies used in the western USA and Australia; as a result, government hydrogeologists tend to prefer large spreading type recharge structures to working with millions of well owners to modify their wells for recharge. India needs to use the vast technological experience of Australia and the USA to design recharge programs but in a manner that incorporates its unique features. While there is no substitute for large spreading-type recharge structures in recharging large confined aquifers, not using millions of farmer-owned open wells for recharge is a great opportunity lost (Shah 2008b).

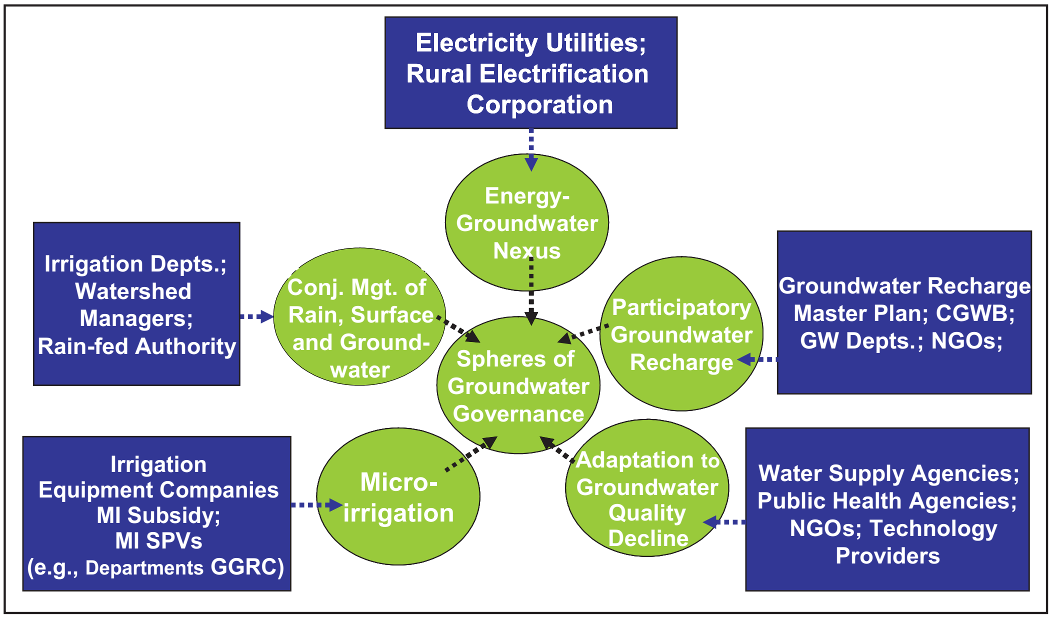
Conclusion: Need for a Paradigm Change

In 2001, India’s Central Groundwater Board produced a Master Plan for Groundwater Recharge (Government of India 2005b). While the plan had many limitations and flaws, its most striking contribution was its objective of stabilizing static post-monsoonal groundwater level throughout India at 3 meters below the ground through a national program of groundwater recharge. Pursuing such a bold objective can be India’s best feasible response to mitigating climatic change as well as adaptation. However, doing this entails a major rethink by India of its water policy and administration.

Reorienting India’s water strategy to meet the challenge of hydro-climatic change demands a paradigm change in the official thinking about water management. Although the groundwater agencies of the government are the custodians of our groundwater resource, in reality, multiple agencies in public and private sectors are major players in India’s groundwater economy. As climatic change transforms groundwater into a more critical and yet threatened resource, there is dire need for coordinating mechanisms to bring these agencies under an umbrella framework to synergize their roles and actions. Even as governments evolve groundwater regulations and their enforcement mechanisms, more practical strategies for groundwater governance need to be evolved in five spheres as outlined in Figure 5 (Shah 2008a). Synergizing the working of agencies in these spheres offers the best chance to bring a modicum of order and method to the region’s water-scavenging irrigation economy.

As of now, managing the energy-irrigation nexus with sensitivity and intelligence is India’s principal tool for the management of groundwater demand. Gujarat’s experiment has already been mentioned earlier; but other ideas need to be tried, given that energy-irrigation nexus holds the key to minimizing C-footprint of Indian irrigation. There has been a debate on the value of aggressively promoting micro-irrigation technologies. Some experts have argued that micro-irrigation technologies, such as drip irrigation, save water that would have otherwise

Figure 5. India’s groundwater governance pentagram.



Notes: Depts. = Departments. SVPs = Special Purpose Vehicles. CGWB = Central Ground Water Board. GGRC = Gujarat Green Revolution Co.

returned to the aquifer for later use. However, in the context of climatic change, micro-irrigation is important for energy savings even more than water savings. Indeed, in the context of climatic change, water management structures and strategies need to achieve joint maximization of water productivity as well as energy efficiency.

In hard-rock India, together with intelligent management of the energy-irrigation nexus, mass-based decentralized groundwater recharge offers a major short-run supply-side opportunity. Public agencies are likely to attract maximum farmer participation in any program that augments on-demand water availability around farming areas. Experience also shows that engaging in groundwater recharge is often the first step for communities to evolve norms for local, community-based demand management.

In alluvial aquifer areas, conjunctive management of rain, surface water and groundwater is the big hitherto underexploited opportunity for supply-side management. Massive investments being planned for rehabilitating, modernizing and extending gravity-flow irrigation from large and small reservoirs need a major rethink in India. In view of the threat of climatic change, India needs to rethink our storage technology itself. Over the past 40 years, India's land mass has been turned into a huge underground reservoir, more productive, efficient and valuable to farmers than surface reservoirs. For millennia, it could capture and store little rainwater because in its predevelopment phase it had little unused storage. The pump irrigation revolution has created 230-250 km^3 of new, more efficient storage in the subcontinent. Like surface reservoirs, aquifer storage is good in some places and not so good in others. To the farmers, this reservoir is more valuable than surface reservoirs because they have direct access to it and can obtain water on demand. Therefore, they are far more likely to collaborate in managing this reservoir if it responds to their recharge pull (Shah 2008 forthcoming).

In mainstream irrigation thinking, groundwater recharge is viewed as a by-product of flow irrigation, but in today's India, this equation needs rethinking. Increasingly, the country's 250 odd km^3 of surface storage make economic sense only for sustaining on-demand groundwater irrigation in extended command areas. A cubic meter of recharged well water, available on demand, is valued many times more than a cubic meter of water in surface storage. Farmers' new-found interest in local water bodies throughout semiarid Peninsular India reflects the value of groundwater recharge. This is evident in South Indian tank communities that are converting irrigation tanks into percolation tanks, and in Saurashtra and Kutch, where a new norm intended to maximize groundwater recharge forbids irrigation from small surface reservoirs so that recharge gets maximized.

In some areas of India with massive evaporation losses from reservoirs and canals but with high rates of infiltration and percolation, the big hope for surface irrigation systems—small and large—may be to reinvent them to enhance and stabilize groundwater aquifers that offer water supply close to points of use, permitting frequent and flexible just-in-time irrigation of diverse crops. Already, many canal irrigation systems create value not through flow irrigation but by supporting well irrigation by default through farmers investing in tube wells in command areas. But canal systems need to be redesigned for maximizing recharge over a larger area than the command. While farmers are doing their bit, the management of the system itself tends to be totally antithetical to optimal system-wide conjunctive use (Shah 1993). Management of surface systems is clearly in dire need of reinvention.

Surface systems in water-stressed regions of western India need to be remodeled to mimic the on-demand nature of groundwater irrigation. In Rajasthan’s Indira Gandhi Canal, the government is subsidizing farmers to make farm ponds, to be filled by the canal once a month and then used to supply water on demand. Gujarat is following suit through a new program of supporting farmers in command areas to build on-farm storage from which they can irrigate on demand. Integrating large canal irrigation projects in the groundwater irrigation economy may support the case for rethinking their modernization in ways previously unimagined. Replacing lined canals with buried perforated pipes connected to irrigation wells or farm and village ponds, thus creating recharge paths along the way, may be a more efficient way of using surface storage than flow irrigation.

There is a new groundswell of enthusiasm for pipes rather than for open channels to transport water. The use of pipes for water transport is also valued for at least two other benefits: first, saving scarce farmland otherwise used for watercourses and field channels, and second, micro-irrigation. In the Sardar-Sarovar Project in Gujarat the major water user associations refused to build water distribution systems because of land scarcity. In an agrarian economy with already high population pressure on farmland, flexible pipes for water distribution make more sense than surface channels, and buried pipes are even better. Pipes also support micro-irrigation technologies. This is what explains a boom in the use of plastics in many parts of Indian agriculture. And if China’s experience is any guide, this boom will continue to generate water as well as energy savings.

By far the most critical response to hydro-climatic change in India’s water sector demands exploring synergies from a variety of players for a nationwide groundwater recharge program. Evolving a groundwater recharge strategy appropriate to India needs to begin with an appreciation of the variety of actors that can contribute through different kinds of recharge structures as suggested in the following table. Public agencies with strong science and engineering capabilities need to play a major role in constructing and managing large recharge structures. However in India, an intelligent strategy can also involve millions of farmers and householders—and thousands of their communities—each of whom can contribute small volumes to recharge dynamic groundwater. When we approach the problem thus, new strategic avenues present themselves. India’s water policy has so far tended to focus on what governments and government agencies can do. Now, it needs to target networks of players, each with distinct capabilities and limitations. If groundwater recharge is to be a major response to hydro-climatic change, the country needs to evolve and work with an integrated groundwater recharge strategy with roles and space for various players to contribute.

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Is It Possible to Revive Dug Wells in Hard-Rock India through Recharge?

Discussion from Studies in Ten Districts of the Country

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Abstract

Groundwater exploitation in hard-rock India is leading to high distress amongst farmers. Various water conservation schemes have been tried and piloted, but no idea has scaled up to the national level. An idea of revitalizing groundwater use, individual as it is, and if still individual-based, could possibly succeed. Recharging through dug wells is one such thought. After mass movements in Saurashtra in the mid-1990s, no effort has been made to promote the idea nationally, till now. The current national program on artificial recharge of dug wells hopes to do so. But this idea can succeed only if farmers see any value in it and try to make it successful. A survey of 767 farmers owning dug wells in 10 districts of India shows that there is immense potential in, yet constraints to, dug-well recharge. A comparison of dug-well recharge with the average annual natural recharge over hard-rock areas of 116 mm shows that there is almost an equal potential in recharging groundwater irrigated areas through dug wells. Surveyed farmers also expect a great increase in water availability, especially during the dry seasons. However, farmers are wary of this recharged water flowing across to their neighbors. They expect to gain around 30% from their recharged water, but agree that there would be a common gain by recharging groundwater together with their neighbors. The farmers' estimated cost of Rs 10,000 for the recharge structures is not such a big constraint, nor is siltation, for which they suggest numerous innovative solutions. Managing dug-well recharge locally is critical. Should it become mandatory for farmers to apply in groups of 10, as our sampled farmers suggest? Should the national program be structured such that farmers are transferred the subsidy and they can construct the structures in April or May as they unanimously prefer to do? Instead, should the policy be to promote local businesses around recharge, so as to harness the experience of well drillers, who also operate during the same summer months?

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More such tuning is needed over implementation of the dug-well recharge program to create demand from farmers, catalyze enterprises locally around recharge and establish monitoring programs to measure the benefits from the first upcoming season in 2009 over lakhs of recharge structures.

Introduction

The existence of individual farm-based irrigation facilities has been one important reason for the increase in irrigated areas in India for the past 3-4 decades. Whether the water for this irrigation comes from a reservoir or from the ground beneath, the farmers are at ease when they do not have to depend on a faraway control for irrigating their fields. This facility however comes with its drawbacks. On the one hand, it gives the farmers the luxury of adjusting their times towards their field activities and, on the other, it also puts the entire onus of assuring water availability to the farmers. This was fine in the initial years of groundwater development, but not so now. The boom, peak and burst of the groundwater revolution are now well known. The farmers, especially in the hard-rock regions are desperate. After expectations that arose from rising incomes due to groundwater-based irrigation, they now face prospects of even more investment, greater risk and uncertain yield (NIH 1999). This crisis has led to distress and agony in the farmer community, who wish, but without hope, towards some strategy to salvage their irrigation infrastructure (Janakarajan 1999).

Spreading canals all across this landscape is not a viable option given numerous physical and economic constraints. Debates often travel towards local options for water capture and on that front, numerous efforts have been initiated. But unlike the development of groundwater irrigation as an individual effort, these local efforts at water conservation have been primarily community efforts requiring collective action by a group of people. Hard as it is to sustain such efforts, much energy often goes towards bringing about such community action. Is there any individual alternative by the farmers themselves that can help in water conservation and sustaining the groundwater-based irrigation?

The Central government has initiated the national program for artificial recharge through dug wells in primarily hard-rock districts of the country which also experience a high stage of groundwater exploitation. It is anticipated, over different phases, to utilize several million wells (aimed at 4.55 million) as recharge structures (Shah 2008; Mohandas and Gupta 2009). Most of these wells are located on private land owned by farmers. The recharging of these private wells is being coordinated by state-wide implementation structures that differ from one state to another. Currently, i.e., early 2009, the two states that have gone on an overdrive for this program are Tamil Nadu and Gujarat. Other states are in earlier stages of organizing the implementation structures, identifying beneficiaries and going ahead with execution. By the monsoon of 2009, a few lakhs of wells would be covered by this program. The monsoon will provide us with pointers for testing this idea and its future potential.

The final end point and, in fact, the most crucial point in this entire structure is the well-owning farmers. Once a recharge structure is attached to a farmer’s well, utilizing this facility to perform recharge or enhancing and maintaining it in the future rest mainly with the farmers.

What do the farmers think of such a mode of doing recharge with their wells? Do they feel there is a significant potential benefit to themselves (and others) by such recharging? Do the farmers have other models and ideas to contribute?

Should such questions have preceded the implementation of the national program itself? Currently, the program is structured so that there is identification of farmers, transfer of funds and expectation that farmers would construct recharge structures. There is less thinking on how village-level implementation should proceed and what support will be available to the farmers during and after construction of recharge structures.

In the past, success of such mass ventures by the farmers has proceeded only due to innovation by farmers themselves. The Saurashtra well recharge movement, which later on provided a base for community action on the check dam movement, succeeded because of a massive communication program by civil society groups that highlighted the need for water conservation amidst several years of drought. Farmers, charged by the idea went ahead and invested their own money and effort towards constructing recharge structures for their wells. Even today, much experience gained from these experiments in the mid-1990s is helping the farmers in Saurashtra to acquire higher yield of water in different ways (e.g., through horizontal bores, etc.).

If an idea such as having distributed recharge of dug wells across the country needs to succeed, it needs to start from the farmers' need and thinking, and channeling it in this direction. For that, it is first essential to know what the farmers think about this idea and how much benefit they would accrue from it.

Worldwide, the need for enhancing recharge to groundwater started being felt on a large scale in the early twentieth century (Todd 2004), and especially in the US, various experiments have been carried out continuously for many decades. These experiments have established different ways of doing recharge – basin-spreading, stream channeling, well recharging, etc. California in the western US has been a pioneer in artificial recharging. Most of recharging in California takes place through basin-spreading in areas such as the Santa Clara aquifer. There are also well-recharging experiments conducted in the coastal areas to prevent ingress of saline water into freshwater aquifers. The source water for recharge is not only through rainfall runoff but also through imported water supplied by canals as in the case of the Santa Clara aquifer. Interestingly, 2,000 wells in a Basaltic aquifer have been used for recharge in southern Idaho Snake Plains aquifer where the fractured rock provides ample space for recharge. These experiments from the US have given some estimates on recharge rates after experience over several decades. Todd reports some of these recharge rates that generally hover around a few thousand cubic meters per day but with high variation from 200 m^3/day to 50,000 m^3/day.

In the Indian context, water harvesting and the concept of groundwater recharge are deep-rooted in cultural practices (Rosin 1993). Today, many NGOs, private consultants and farmers have been trying out different types of well-recharging efforts. The technologies are highly varied with much action on the ground. However, to have millions of farmers take up recharging on their dug wells requires a massive participation from the farmers themselves. This study has been designed to gauge how farmers themselves perceive the value of their dug wells, if they see recharging as an effort worth enough and how they see the possible benefits from recharging. The purpose is to provide constructive inputs to current efforts in this direction.

The Larger Picture

Before going ahead into issues regarding well recharge, let us look at the large-level potential of this idea. For this we utilize published data from the Central Groundwater Board (CGWB 2004). Nationwide data on groundwater balance on district levels are available from this publication. Using this we have earlier categorized and added layers of similar district-level data to create a large data set on groundwater, agriculture and related information (Krishnan et al. 2007). One of the layers added was the hydrogeology of the district. For our analysis here, we take only those districts which have more than 75% of their area in either Basaltic or Crystalline Granitic formations. In our data set, we have 112 such districts spread across mainly 11 states. The total annual groundwater recharge across these 112 districts is equal to 10,141,965 ha.m and the total area of these districts is 87,342,454 ha. This gives a recharge per unit area of 0.116 m^3/m^2, i.e., 116 mm of recharge per unit area. This is an average value over this entire hard-rock region of the country; therefore, it will show variations depending on regional factors such as rainfall, infiltration properties, etc. However, it gives us a rough number useful for discussion. Note that this recharge is subject to base flows and other natural flows and, therefore, the net available groundwater is a lesser quantity.

Table 1. Dug-well densities in wells/ha of groundwater irrigated area for different river basins.

Cauvery	ERF_Bet_Go_Kr	ERF_Bet_Ma_Go	ERF_Bet_Pe_Ca	ERF_Sca	Ganga	Godavari
0.52	3.69	2.10	1.35	1.33	1.09	2.12

Krishna	Mahanadi	Mahi	Narmada	Pennar	Sabarmati	Subarnarekha	Tapi
0.73	3.52	1.79	0.88	0.36	1.19	2.41	1.14

Now consider a dug well of 20 m depth with a diameter of 8 m, i.e., a total volume of roughly 1,000 m^3. If this well is used as a recharge well and fills to capacity once a year, then the volume of recharge is equal to 1,000 m^3 (we use representative dimensions due to lack of availability of national level data on well dimensions).

Further, we used data from the Agricultural Census 2001 on the number of dug wells. We obtained data from the same 112 hard-rock districts on the number of dug wells and net area irrigation by groundwater irrigation.

Table 1 shows the well densities calculated for each river basin only across the hard-rock districts. The minimum well density is reported for the districts lying in the Cauvery River Basin, i.e., 0.52 dug wells/ha of groundwater irrigated area and a maximum of 3.69 dug wells/ha for the east flowing rivers lying between Godavari and Krishna.

The total number of dug wells in these 112 districts is equal to 4,257,918 supposedly irrigating 5,420,434 ha. No doubt, these data have errors, especially in the data on net irrigated area (Dhawan 1990). But we use these here due to lack of alternatives and to get rough values. The average dug well density is 4,257,918/5,420,434 = 0.78 wells/ha over these 112 hard-rock-dominated districts.

The effective recharge per unit area of this dug well is therefore as follows:

Recharge per unit area = Recharge from single well * well density

That is, 1,000 m^3 * 0.78/10,000 m^2 = 0.078 m, i.e., 78 mm, i.e., 67% of the current recharge.

But what are the assumptions here? We are assuming that this 1,000 m^3 of recharge would have otherwise flowed downstream without recharging into any downstream aquifer. We are assuming that the net base flows or natural flows from recharged water would be the same as before so that there is an increase in water availability with this additional recharge. Also assumed here is that it is possible to recharge using dug wells during storm events, in spite of any water-level increase (by a Hortonian or Dunne mechanism;[2] a hydrologic way of putting a common sense question: "How would water recharge from wells during rains when water level rises so much close to the surface?"), a point which is countered by some observers especially in the hard-rock areas (Kumar et al 2008).

Also assumed are the quality of water recharged through the dug well which if silt-loaded could reduce infiltration through the well. In short, if all these assumptions are valid, we have a potentially powerful idea of using dug wells for recharging the aquifers and augmentation of current recharge by a significant amount. That is, of course, if a lot of wells do such recharging.

Debates Surrounding Dug-well recharge

Discussions surrounding such a distributed mode of groundwater recharge through dug wells center on some key issues:

1. Is there surplus runoff available for recharge through dug wells? Would this water recharge into the aquifer downstream through ponds, etc.?
2. Considering that this recharge water also carries silt load (and agrochemicals) would the pore spaces close to the well get choked?
3. Would we ever have a mass number of recharge wells in place to achieve a significant increase in water availability?
4. During monsoons, when recharged water already saturates the low specific yield aquifers is there more space left at all?

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[2] There are two main theories explaining surface runoff in catchments. The classical *Hortonian mechanism* propagated by Horton describes runoff as the excess water beyond the infiltration capacity of the soil (Horton 1945). The infiltration capacity reduces with rainfall and after a sufficient time, it is limited by the vertical hydraulic conductivity of the soil. In this conceptualization, if the rainfall rate is above this infiltration limit, runoff occurs. The classical theory of runoff considers this mechanism to be uniform over the landscape and the varying runoff patterns are explained by the variations in precipitation and in local soil conditions. However, such conditions were observed to be true mainly in semiarid catchments with a deep water table. In field conditions, this theory failed to explain phenomena such as pockets of runoff generation from local depressions and from hollows. An alternative mechanism was proposed by *Thomas Dunne* in the 1970s according to whom runoff occurs when locally the water table rises to the surface (Dunne and Black 1970). Such locations are generally depressions and topographic hollows that are recipients of subsurface flows. In such locations, the water table is locally at the surface and any precipitation has to flow as surface runoff. These two mechanisms: infiltration excess overland flow and the saturated overland flow together explain most types of surface runoff observed in small catchments that finally lead onto larger streams and rivers.

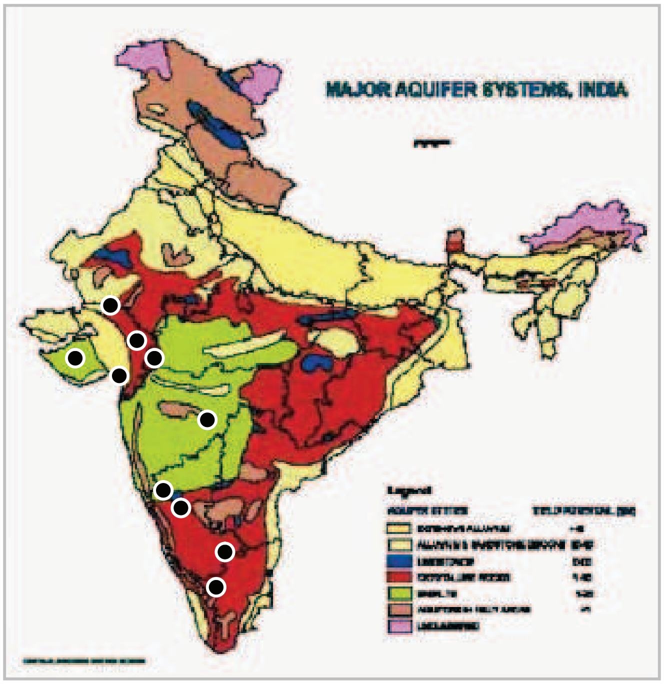
Given such questions, we have designed this study to answer some of them:

1. What are current strategies being adopted by farmers for innovative management of dug wells in hard-rock areas?
2. What potential further exists for innovative strategies such as recharge of dug wells? How do farmers perceive the potentials benefits and risks in such strategies?
3. How can dug-well recharge programs be best implemented in hard-rock areas of the country?

These studies were performed in 10 districts along with partners. Gadag (G) and Haveri (H) districts of Karnataka; Anantapur (A) in AP; Jhabua (J) and Dewas (D) in MP; Rajkot (R) and Khambat (Anand), (K) in Gujarat; Yavatmal (Y) in Maharashtra; Dungarpur (D) in Rajasthan and Dharmapuri (D) in TN with 5 villages chosen at each site. Appendix 1 gives the names/organizations of the research partners for our study. A planning workshop was conducted in mid-December, 2008 to discuss issues and arrive at researchable points. The finalized methodology was designed and fieldwork started by the end of December till the end of January, 2009.

The study areas are all located in either Basalt or Crystalline rock areas of the country except for Khambat, which is a saline-affected coastal alluvium area where the dug-well recharge program of the government is being implemented (Figure 1).

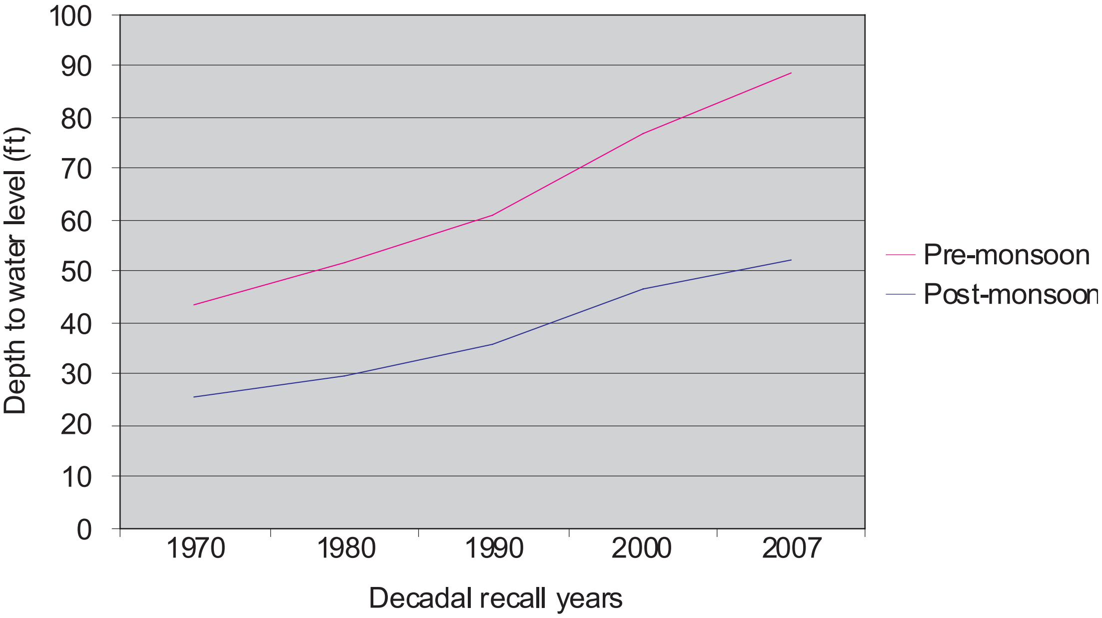
Figure 1. Locations of sites overlaid on the hydrogeology map of India.



Source: Aquifer systems map is from cgwb.gov.in/images/aquifer_map.jpg

Figure 2 shows the trend in average pre- and post-monsoonal depth to water levels over the study sites. These values have been obtained as recollected knowledge during group discussion in each of the five study villages of each site. Since 1970 there has been a steady perceived drop in water levels by roughly 4-5 feet per decade. Along with this, as reported by the sampled farmers, the number of dug wells has increased but has been overtaken by bore wells in the past 2 decades.

Figure 2. Average pre- and post-monsoonal depth to water table in dug wells as reported by group discussion in the study sites in 1970, 1980, 1990, 2000 and 2007 seasons.



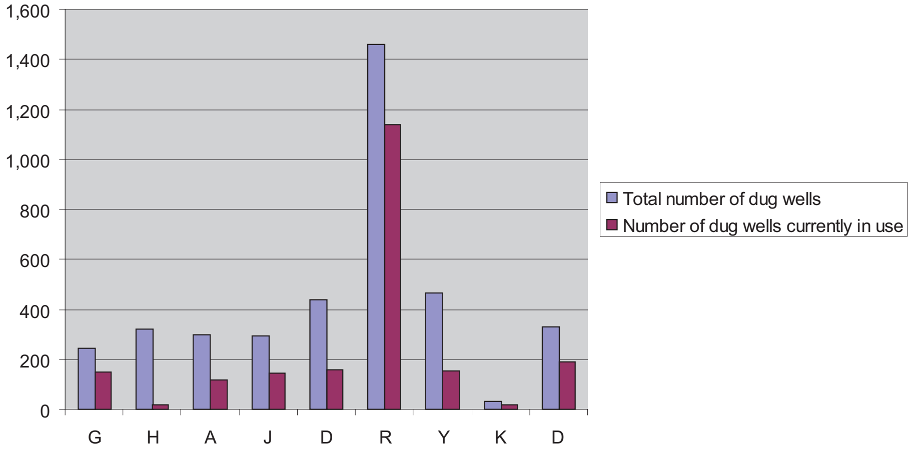
Roughly 42% of dug wells and 48% of bore wells are abandoned. This reflects the massive investment by farmers which has now gone waste because of fall in water levels and greater competition for water from new irrigation wells in the study villages.

Volume of Wells and Perception on Recharge Potential

Data on well dimensions are lacking from any of the surveys conducted by different agencies. Volume of well storage is important in determining the total capacity of recharge possible from wells. However, this alone is not sufficient. The rate of recharge, especially during storm events is crucial. Studies indicate that in some hard-rock areas, the water level shows a sudden rise up to the ground level during rainfall events. This might be due to the Dunne type of runoff mechanism prevailing in such watersheds. In such cases, the rate of infiltration from wells would drop down rapidly and recharge would not be possible till the water level drops down again. Here, we utilize the farmers' own observations of drainage time from their wells to calculate the average recharge rate possible from their wells.

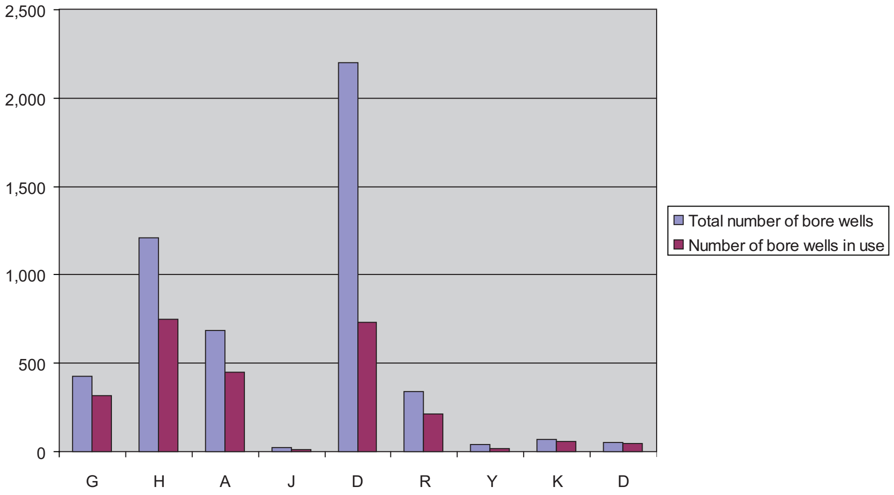
Figure 3. Currently existing and in-use (a) dug wells, and (b) bore wells, for different study sites.

(a)



Note: For both figures 3a and 3b, letters in the X axes denote the first nine study sites given in Table 2.

(b)



We sampled 800 wells whose average depth and average diameter are 41 ft. and 12.6 ft., respectively. There is variation in well size from site to site, with a maximum diameter of 60 ft. in the Haveri District in north Karnataka.

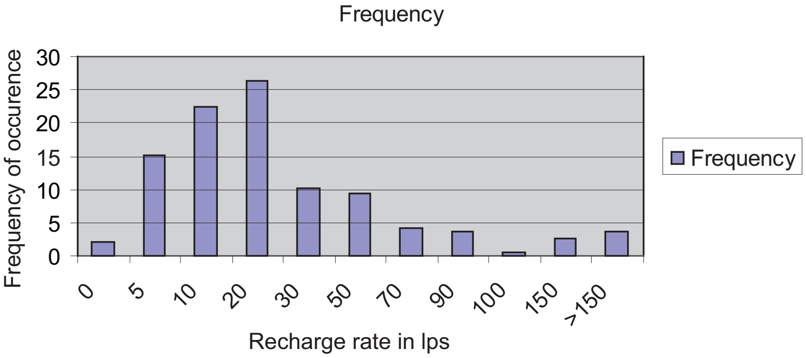
Table 2 shows the volumes of wells in cubic meters calculated from our field studies in eight sites. The average volume from 767 wells is 467 m^3. Also collected is the time it takes to drain out the well completely which is 30 hours on average. The drainage or recharge rate shown in Table 3 is calculated as volume of well/time of drainage.

Table 2. Volumes of wells (in m^3) calculated from different study sites.

Gadag	Haveri	Anantapur	Jhabua	Dewas	Rajkot	Yavatmal	Khambat	Dungarpur	Dharmapuri
327	820	1,067	215	507	192	234	248	327	440

The distribution of reported recharge rates from sampled wells is shown in Figure 4. The reported recharge rates are highly skewed. Since the number is not a typical Cartesian quantity and, in fact, shows a tendency towards log-normal distribution, we take the exp(average(log(Recharge Rate))) instead of the more commonly used simple average that exaggerates the extreme high values (Tarantola 2005). We get this transformed average value as 3.22 liters per second (lps). The minimum average of 2.6 lps was reported from Anantapur and the maximum average of 6.05 lps from Dewas.

Figure 4. Cumulative frequency of recharge rate in l/s from sampled wells.



Athavale (2003) reports a recharge rate of 225 m^3/day (2.6 lps) from a recharge well in central Mehsana in 1983, 192 m^3 /day (2.22 lps) and 2,600 m^3/day (30 lps) from injection methods in coastal Saurashtra, 45 lps from a pressure injection test by the Gujarat Water Resources Department near Ahmedabad city in 1974, 43.3 lps from an injection experiment using canal water in Haryana by the Central Groundwater Board. All these experiments were conducted in primarily alluvial aquifers. For hard-rock aquifers, the National Geophysical Research Institute experiment in Anantapur showed a recharge rate of 40 lps.

As compared to these numbers, Todd reports recharge rates varying from 2.3 lps to 570 lps. It should be especially noted that in hard-rock areas the presence of veins or fractures near the recharge well can carry off the recharge water into a deeper aquifer and can impact the recharge rate to a great extent. The distribution of values of recharge rates will show high skewness across wells.

Table 3. Well recharge rates (in lps) reported from study sites.

Gadag	Haveri	Anantapur	Jhabua	Dewas	Rajkot	Yavatmal	Khambat	Dungarpur	Dharmapuri
3.46	3.1	2.62	3.4	6.05	2.56	1.15	1.63	2.71	4.54

Next we also collect data on the number of times farmers perceive their wells to fill up during the monsoon if recharged. This is a purely estimated quantity since farmers have not yet experienced such recharge.

Table 4. Expected number of times wells would drain out with recharged water annually

Gadag	Haveri	Anantapur	Jhabua	Dewas	Rajkot	Yavatmal	Khambat	Dungarpur	Dharmapuri
0.63	0.715	7.78	3.58	2.5	2.89	1.61	0.96	3.1	2.8

The average number of times of recharge is 2.83. Using the volumes of wells and the number of expected times of recharge, we compute the expected volume of recharge as well volume * expected number of times of recharge.

Table 5. Expected volume of recharge from dug wells (in m^3) annually.

Gadag	Haveri	Anantapur	Jhabua	Dewas	Rajkot	Yavatmal	Khambat	Dungarpur	Dharmapuri
198.27	561.75	8,578	876.73	1,361.93	559.47	363.37	233.403	1,030.18	1,112.17

The average recharge volume of wells is 1,591.62 m^3. Using this average recharge capacity of the dug well in our initial calculation on potential of such recharge, the result is: 1,591.62 m^3 * 0.78 / 10,000 m^2 = 0.124 m, i.e., 124 mm, which come to 7% more than the average current recharge calculated previously as 116 mm. This is a really significant number; in other words, the average recharge over groundwater irrigated hard-rock areas can be increased by over 100%, but as mentioned in the earlier parts of the paper, we can make this statement over several assumptions.

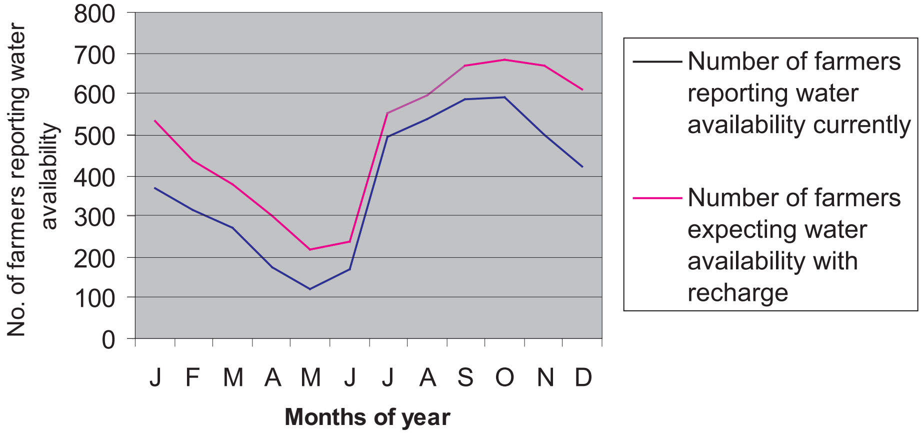
For the 112 districts, if there are 4.25 million wells recharged, then we will have, the following results: Total recharge = 4.25 million * 1,000 **m^3,** i.e., 4.25 billion **m^3** of recharge.

Altogether 101 billion m^3 of recharge are occurring annually over these 112 districts (CGWB 2004), i.e., a net increase of around 4% over this total groundwater recharge. Considering only the groundwater irrigated areas in these districts, we have a total of 9.99 m^3 of recharge occurring now. So we have a potential net increase of 42%.

Next, Figure 5 shows the number of farmers in our sample of 900 who perceive water to be available in their wells in a particular month with and without recharge. On average, there is a 36% increase in the number of wells which are expected to increase water availability with recharge. This increase is more in the dry seasons than in the wet seasons. It reflects more the need that people wish with the recharge, and less with what would actually happen.

What is sure from these expected potential benefits of recharge is that there is a demand from farmers for such an option. The numbers reported here are perceptions and results of a survey and are therefore not to be taken as actual figures. However, in the face of lack of such information, this is the best we have, at the least indicating the farmers' potential hope with dug-well recharging.

Figure 5. Number of farmers reporting water availability in their dug wells currently and with recharge



The question now is what are the constraints to going ahead for recharge? Why are farmers not implementing recharge structures by themselves when they come to know about them? As compared to the cost of enhancements to the well, such as deepening and boring, the cost of constructing a recharge structure is not too high. If the farmers feel that this would be beneficial, they would have gone ahead by themselves. So, what prevents them from doing so?

Constraints to Implementing Recharging of Dug Wells by Farmers

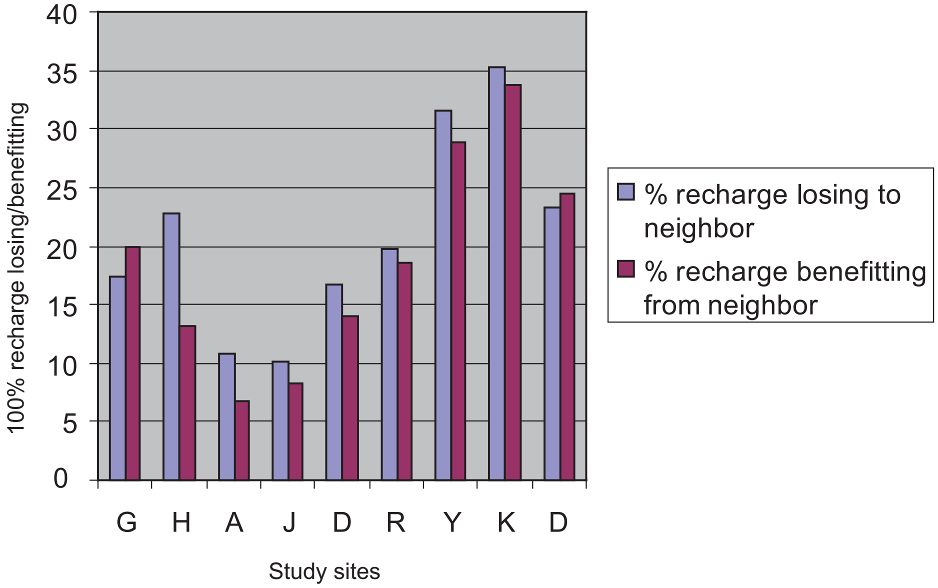
One constraint to farmers adopting dug-well recharge is their perception about whether the recharged water would be available to them for pumping. Naturally, if there are conduits for water to flow across to other nearby wells, they would be disinclined to recharge. This was evident from our survey. Moreover, if there are deeper wells nearby, one would be less inclined to recharge.

Our sample of 767 farmers feel, on average, that their water yield reduces by 16% on average and the level of their well water goes down by 4 ft. when their neighbors pump from their wells. Therefore, there is always this perception of sharing a common aquifer; this perception is carried over to recharging too.

Except for one, all sites see a greater expectation of loss of water to neighbors rather than gain from neighbors by recharging. In general, there is no reason to expect this over a reasonably large data set, but here we see a common trend (except for the first site) of greater expectation of loss. This is a sure impediment to recharge. Unless the neighbors also recharge, the present farmers would not take much effort towards recharging.

There is wide variation over the well construction and estimated costs of well recharge structure which average to around Rs 10,000, i.e., Rs. 6.28/m^3 of annual recharge (from previous calculation of average recharge = 1,591.62 m^3/well). That itself is a significant investment since the returns from recharging are not as directly evident as those from, say, well deepening. There is always the risk that the water that is being recharged would not be available to oneself. Further, around 60% of the sampled farmers report that the water collection points in or near their farms lie above (in terms of elevation) their wells. This means that either they use a field channel or more surely, make arrangement for underground boring to transmit water to their

Figure 6. Expected percentage loss of recharged water to neighbors or benefits from neighbors across different sites.



Note: The letters in the X axis denote the first nine study sites given in Table 3.

wells. Such types of underground boring to transmit water to the wells for recharging have been in vogue in parts of Saurashtra. But that involves a further investment of say, Rs 5,000, or more. Around 45% of the sampled farmers report that they would require investing on such type of underground boring and pipes.

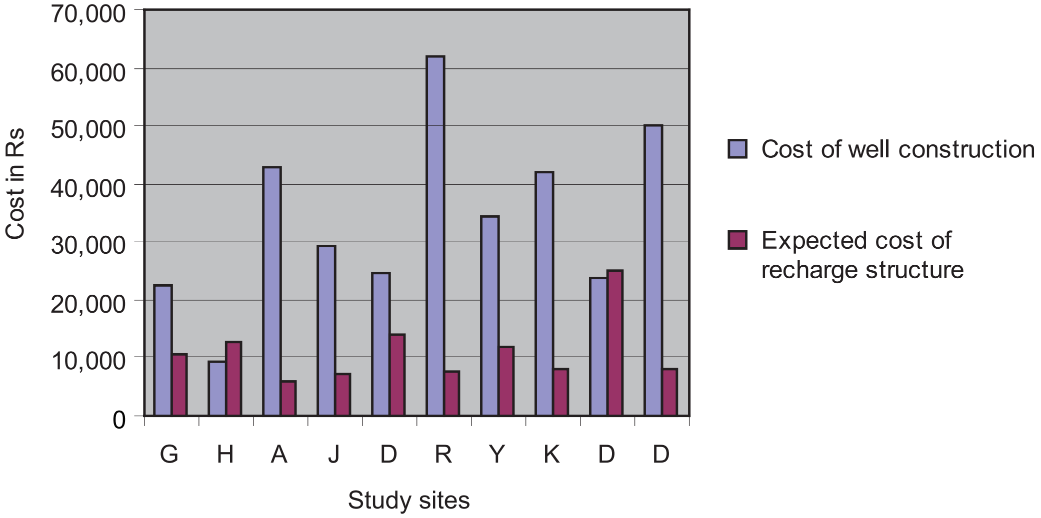
An unexpected problem reported by farmers is the possible caving in of the well, especially in unconsolidated formations. Some farmers feel that since the recharged water falls to the bottom of the well from a height, it could deepen the sides of the foundation of the well resulting in caving in of the well. In this context, care has to be taken to let the water flow along the sides of the well so that it does not create an impact at the bottom.

Siltation is reported as a potential problem by 67% of sampled farmers. But they also mention numerous innovative ways to counter siltation, e.g., using mosquito nets, planting thorny shrubs to capture waste, small bunding to arrest direct transport of silt, etc. Farmers seem confident that siltation, though a problem, can be countered.

All these are reflected in the choice of farmers when asked what they would do with Rs 4,000. Around 45% of farmers chose recharging, while 43% chose to deepen their wells. Well deepening is psychologically an accepted proposition for an individual private well owner to invest in for increasing well yield. On average, farmers in our sample have spent Rs 16,200 for well deepening.

Here some points of comparison can be made between recharging and well deepening as investments for increasing well yield. The more the farmers invest on wells the greater the increase of their risk. Each additional investment is a sort of “protection” for all earlier investments made on the well. There is always a chance that with one additional deepening, the well yield will suddenly increases significantly. The farmer is playing a risky game, and with each additional investment, the game gets riskier. Additionally, the larger the number of farmers investing in deepening the greater the reduction of the benefits to individual farmers.

Figure 7. Reported average costs of well construction and average estimated local costs of recharge structures.



Note: The letters in the X axis denote the study sites given in Table 3.

This logic gets reversed in the case of well recharging. If farmers recharge instead of deepening, there is increasing individual benefit when more farmers recharge. One gains when others invest too. Up to a limit, there is decrease in risk with each additional investment.

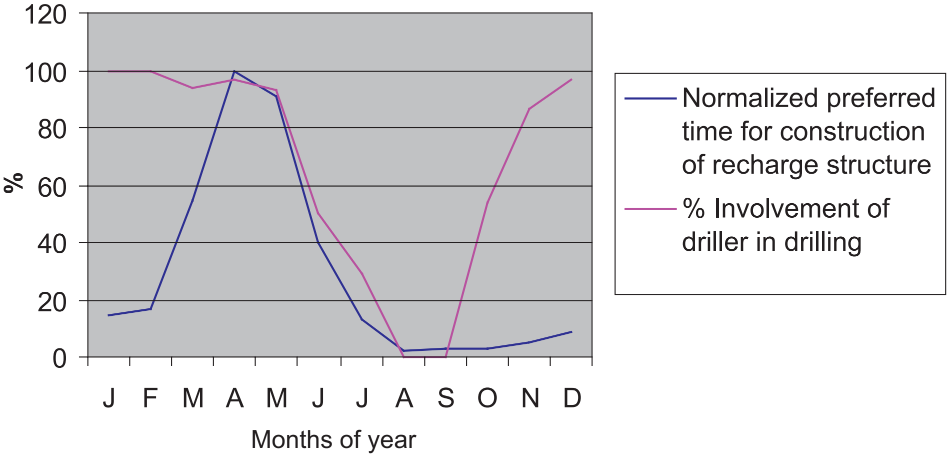
Therefore, the economics of well deepening and recharging are diametrically opposite to each other. Somewhere there is a balance, which is currently tilted towards well deepening. The stage is therefore set for more recharging.

Management of Recharge Structures

Perceiving recharging as one means of resuscitating dry or semidry dug wells, it seems possible that the current mode of implementation of the national program on artificial dug-well recharge would face some constraints. To begin with, expecting individual farmers to construct recharge structures with a subsidy of Rs 2,000 or Rs 4,000 means that the program has sufficient interest in the farmers. Enabling recharge is not just about constructing the structure, but also making flood water pass through it, cleaning the structure of silt and other waste that collect near it and making repairs when required. All these need a proactive farmer who sees a benefit, common if not personal, in recharging.

As opposed to just 20-30% of benefit if a neighboring well recharges, almost all farmers agree that if they as well as their neighbors recharge there would be benefit to all of them. Further, 93% of sampled farmers felt that it would be good if farmers applied for recharging as a group, even though they implement it individually on their wells. They reported that an average of 10 farmers should apply together for recharging. The number 10 probably comes form their intuition of finding a balance between the hassle of arranging a group application and the benefit of larger numbers of farmers recharging together.

Figure 8. Comparing preferred time for constructing recharge structures and times of well construction.



Farmers are also accepting alternative ideas for recharge. Gujarat farmers in our sample were already practicing recharging of dug wells using canal water. This was very much so in the Mahi tail command area of Khambat where the Irrigation Department has innovated a unique mode of water distribution through underground sumps. The canal water is used by farmers for recharging their dug wells, a practice being followed for at least a decade. On average, farmers reported that they could spend up to Rs 5,000 towards pipes and other material, if there was a scheme at recharging their wells through canal water. However, such a scheme is not possible at many places since such canal water is not available everywhere. Mention must be made here of a similar mechanism of water distribution being followed currently in the Sardar-Sarovar command area of Gujarat where farmers have been spending as much as Rs 1,000-5,000 per ha towards pipes and pumps for accessing water from the branch and minor canals.

The timing of constructing recharge structures is also critical. The structure needs to be constructed before the monsoon, before a sufficient period so that there is time for the concrete to cure and stabilize. April was reported to be best month for constructing recharge structures and, on average, 12 days, were reported as necessary to construct the structure. April is also a time when construction of wells is at its peak. This brings us to an interesting link between well construction and well recharge. Figure 8 compares the relative yearly schedules of well drillers with the reported preference of farmers for constructing recharge structures. The graph points to April as a time when drillers are engaged in well construction, so why not involve them in constructing recharge structures too?

We interviewed 30 drillers across the sites about their views on recharging as an option for dug wells. Interestingly, drillers too report an average of around Rs 10,000 for constructing the recharge structures. They slightly prefer May to April as the best time for constructing the structures, and suggest a higher number (22, on average) of farmers to recharge together for getting greater benefit, perhaps discounting the hassles in group applications by farmers. However 2/3 drillers showed interest in participating not only in taking up constructing recharge structures as a business but also playing a role in monitoring them and seeing the impact from the monsoon. On average, they report the need to charge Rs 8,600 for constructing a recharge structure and also showed interest in getting trained on these aspects. Well drillers, especially in the hard-rock areas, show a high sense of local knowledge in their areas as shown by previous studies (Krishnan 2008; Krishnan et al. 2009): so why not utilize their expertise towards a natural extension of their profession?

What is the best way to do recharge? How much common benefit will it result in? What is the best way to implement the program at the village level? These questions need to be asked more to check the worth of this idea. If it works, farmers will pay and take it up by themselves. Probably the monsoon of 2009 will answer some of these questions.

Thoughts and Ideas

Whether localized governance of groundwater in hard-rock areas is to be pursued is probably not a question today. How to do it comprises the important questions: through pricing (water, energy), legal regulation, or community institutions? Whatever the framework, whether as a combination of these ideas, water supply augmentation and demand management are both to be taken care of, directly through regulation or through indirect instruments such as pricing. Recharge of dug wells offers one option for local augmentation of water supply, an option that deeply involves the ultimate stakeholders, the farmers. Through this mode of supply augmentation by their own efforts, they would perhaps get attuned to thinking about demand management. So far, groundwater has always been sourced from recharge naturally through rainfall or ponds, or from canals. But once the farmers get involved in water supply, it could change their thinking forever. In that vein, recharge of dug wells should be seen within the broader framework of how to address groundwater governance locally and not in isolation.

Records of dug-well recharge could also potentially become an instrument where the records of millions of dug wells can be sequenced and maintained in a database which can be accessed. It could be a means of information exchange from, and to, the farmer. Crucial hydrogeological and hydraulic data can be passed by the farmer, whereas, scientific and policy information can be passed down to the farmer. If this idea is utilized towards these objectives and strengthened through appropriate institutions at different levels, then there is much that can be gained through this program. Dug-well recharge can be the backbone of a mass scientific experimentation involving millions of farmers and giving an opportunity to test many of the new ICT innovations. The Tamil Nadu recharge program is attempting a bit in this direction by maintaining electronic records and hoping to get constant feedback from farmers.

However, in this discussion on dug-well recharge, we should not forget the other competitive ideas which are also being tried today: group-owned wells in tandem with recharge ponds, bore-well recharge, small to large surface water harvesting structures and underground dykes – the list is endless, as many as the different groups that have been experimenting with these ideas. As mentioned earlier, instead of losing ourselves in just one of these possibilities, we need to think on the broader context of how they all fit together, what is relevant where, and how they will enable supply and demand management of groundwater locally.

A last note should be made of uncertainty – both epistemological and experimental; i.e., from methodology as well as data. Within this study, especially when we sample just a few hundred wells out of millions, the question arises of sampling and representativeness of the sample. This, we try to counter slightly, but certainly not in its entirety, by taking two data sets, one over a national level (that is close to being exhaustive, but error-prone), and the other of our own sampled data that have better control of data errors. We have attempted to utilize both these data sets in order to support the analysis in this paper.

The next question on uncertainty and perhaps more important is on methodology. Looking at the physical context, a unit of aquifer of watershed and a time scale observation of a few seasons are essential to make any statement of reasonable accuracy. In hard-rock areas, especially, there have been research groups which have worked on a single 1 km^2 plot of fractured rock for decades in arid Arizona to finally conclude very high uncertainty. Here, we have relied on localized farmers' and well drillers' knowledge gathered through years of observation, but who have had no scientific training. As such, it is subject to opinions, perceptions and biases as opposed to the more objective, repeatable and potentially error-minimizable nature of scientific data. Neither is one a substitute for the other, only complementary. We have therefore, tried to refer to scientific studies and utilize them as much as possible. Any additions on that front would be valuable.

Appendix 1. Research partners for the study.

Site	Research partner
Gadag	Navchetana Rural Dev Society
Haveri	SCOPE
Anantapur	Hirudia Raj
Jhabua	GATE
Dewas	GATE
Rajkot	SAVARAJ
Yavatmal	Vivek Kher
Khambat	INREM, Upen Mahida
Dungarpur	PEDO

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Addressing India's Water Challenge 2050: The Virtual Water Trade Option[1]

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Food Security and Water Transfers

The Government of India, on directions from the Supreme Court in 2002 and advice from the National Water Development Agency (NWDA), proposed an estimated US$120 billion National River Linking Project (NRLP) which envisages linking 37 Himalayan and Peninsular rivers (Figure 1; NCIWRD 1999). Doing this will form a gigantic South Asian water grid which will annually handle 178×10^9 m^3/yr of interbasin water transfer; build 12,500 km of canals; generate 34 gigawatts of hydropower; add 35 million hectares (Mha) to India's irrigated areas; and generate inland navigation benefits (IWMI 2003; NWDA 2006; Gupta and van der Zaag 2007).

The prime motivation behind this grand plan is India's growing concern about the need to produce additional food for its large and rapidly increasing population. The NWDA cites that India will require about 450 million tonnes of food grains per annum to feed a population of 1.5 billion in the year 2050 (NCIWRD 1999) and to meet this requirement, it needs to expand its irrigation potential to 160 Mha, which is 20 Mha more than the total irrigation potential without NRLP. This follows India's long-standing, unwritten policy of food self-sufficiency.

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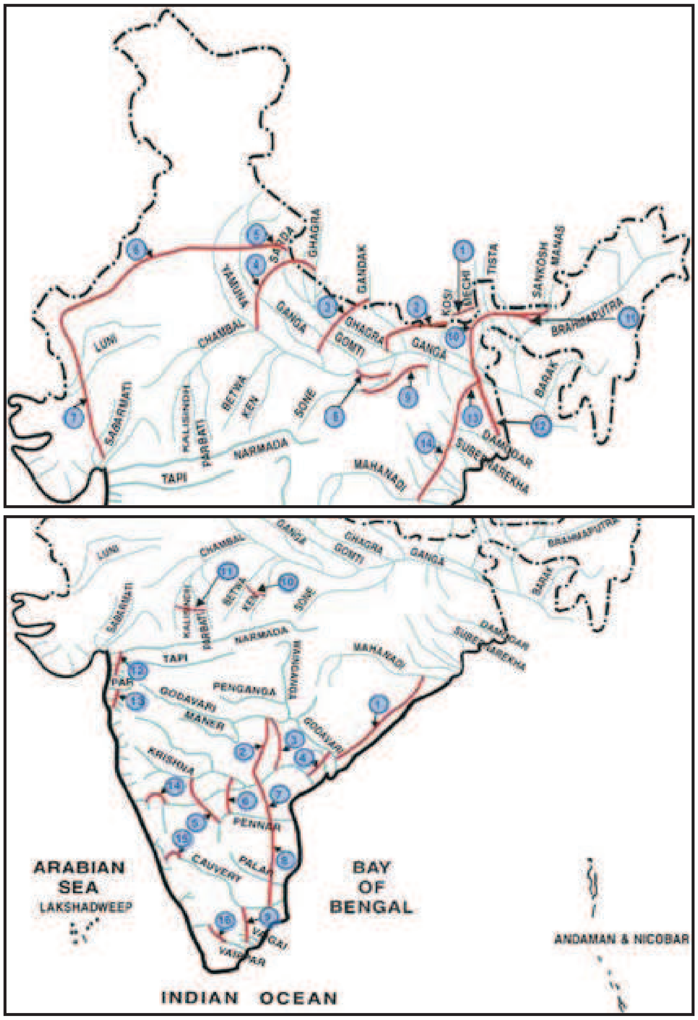
Figure 1. India's proposed National River Linking Project (NRLP), with the Himalayan component (left) and the Peninsular component (right).



Source: Reproduced from NCIWRD 1999.

Considering that large parts of the Ganga-Brahmaputra-Meghna Basin face recurring floods and a number of western and peninsular states face severe droughts, the NWDA (2006) contends that "one of the most effective ways to increase the irrigation potential for increasing the food grain production, mitigate floods and droughts and reduce regional imbalance in the availability of water is the Inter Basin Water Transfer (IBWT) from the surplus rivers to deficit areas.

However, representatives from civil society, the media and academia have strongly criticized the plan (Iyer 2002; Vombatkere 2003; Vaidyanathan 2003; Bandyopadhyay and Perveen 2004; Patkar 2004). Besides voicing concerns about the potential negative environmental impacts of the mega-project, critics have argued that the decision to go ahead with the plan has been hasty. They argue that NRLP is only one of the alternatives to ensure India's food and water security and alternative—local, cheaper and greener—options should have been given more serious consideration. A number of alternatives have been suggested including decentralized water harvesting and artificial recharge of aquifers, improving the productivity of agriculture in water-scarce regions (which, it is claimed, continue to waste precious water resources), improving the efficiency of India's public irrigation systems through involvement of stakeholders in the management of irrigation, and using virtual water trade, instead of physical water transfers, to tackle the high spatial variation in water availability across the country.

While a number of these options seem plausible, all of them require further scientific exploration and study before any one of them (or a combination of several of them) can form a feasible answer to India's impending and formidable water crisis. While the Government of India has failed to share with the public its detailed studies and plans for the proposed interbasin transfers, the opponents of NRLP also do not have a studied program of action to present. The lack of such analyses has led to a polarized and opinionated debate which is preventing the nation from forming a scientific opinion about NRLP and its various alternatives (Verma and Phansalkar 2007).

One of the alternatives to NRLP that has been discussed is virtual water trade within the country. Proponents of this alternative have argued that instead of physically transferring large quantities of water from the flood-prone east to the water-scarce west and south, it would be desirable to transfer virtual water in the form of food grains. This paper explores the factors that influence interstate virtual water trade in India; provides a preliminary assessment of the potential of virtual water trade to act as an alternative to the proposed IBWT; and assesses policy options for promoting and enhancing water-saving trade within the country.

Virtual Water Trade and International Trade Theories

The term 'virtual water' was introduced by Professor Tony Allan (1993, 1994) referring to the volume of water needed to produce agricultural commodities. The same concept has differently been referred to as 'embedded water' (Allan 2003), 'exogenous water' (Haddadin 2003) or 'ultraviolet' water (Savenije 2004). When a commodity (or service) is traded, the buyer essentially imports (virtual) water used in the production of the commodity. In the context of international (food) trade, this concept has been applied with a view to optimize the flow of commodities considering the water endowments of nations. Using the principles of international trade, it suggests that water-rich countries should produce and export water-intensive commodities (which indirectly carry embedded water needed for producing them) to water-scarce countries, thereby enabling the latter to divert their precious water resources to alternative, higher productivity uses.

The concept was later expanded to include other commodities and services (Allan 1998; Hoekstra 2003). Several researchers (Hoekstra and Hung 2002; Hoekstra 2003; Chapagain and Hoekstra 2003; Oki et al. 2003; Renault 2003; Zimmer and Renault 2003; De Fraiture et al. 2004; Chapagain et al. 2005; Chapagain 2006; Hoekstra and Chapagain 2007a,b) have investigated the role that international trade in virtual water can play in attaining global water saving and in ensuring food security in regions facing acute physical and economic water scarcity, especially in the Middle East, North Africa region and southern Africa.

Chapagain and Hoekstra (2004) employed the concept of 'water footprint' to compute nations' dependence on virtual water in the global trade system. Hoekstra and Hung (2002, 2005) quantified the scale and extent of virtual water crop trade globally while Chapagain and Hoekstra (2003) developed the methodology for similar calculations in the context of trade in livestock and livestock products. The two results were then combined to get a comprehensive picture of the total agricultural virtual water trade (Hoekstra and Chapagain 2007a, b). Global water saving from this trade was estimated to be about 455 giga cubic meters (Gm^3) per annum (Oki et al. 2003; Oki and Kanae 2004). However, policy conclusions from these results were suitably moderated by De Fraiture et al. (2004) who noted that global water savings are caused as a result of productivity differences between importing and exporting countries and are only an unintended by-product of international trade in agricultural commodities. Following the same logic, it is also possible to argue that virtual water trade can lead to wastage of water in the situation where countries with low water productivity export virtual water to high water productivity regions.

While a lot has been said about the scope, benefits and limitations of virtual water trade between countries, studies on virtual water movement within countries are, at best, sparse. As mentioned above, for countries such as India and China, it might be misleading to account for them as single entities. This is because even within these huge countries, there are wide disparities in water endowments. In addition, they demand special attention since they are big players in the international food trade, as the percentage of their domestic consumption trade is negligible and both countries are close to food self-sufficiency (De Fraiture et al. 2004). Further, virtual water trade within countries like India sidesteps the debate around food self-sufficiency—which is often used to negate any suggestion of letting the virtual water trade logic to influence India's food trade policies.

Ma and others (Ma 2004; Ma et al. 2006) quantified the virtual water trade within China in the backdrop of the south-north transfer project. The study found that north China exports 52×10^9 m^3/yr of virtual water to south China, a volume which is more than the maximum proposed water transfer volume along three routes ($38–43\times10^9$ m^3/yr) in the south-north Transfer Project. The study therefore concludes that if the "perverse" direction of virtual water trade in China can be reversed, it can act as a better alternative to physical transfer of water across basins. It is with a similar logic that the idea of interstate virtual water trade in India is being proposed as an alternative to NRLP.

The Economic Logic behind Virtual Water Trade

Theory of Comparative Advantage

Hoekstra (2003) referring to Wichelns (2001) observed that "the economic argument behind virtual water trade is that, according to international trade theory, nations should export products in which they possess a relative or comparative advantage in production, while they should import products in which they possess a comparative disadvantage." Thus the logic of virtual water trade follows Ricardo's theory of comparative advantage which focuses on trade based on differences in production technologies and factor endowments. It states that each country should specialize in the production of such goods and services and export them to other countries and that in the production of these each country enjoys a comparative advantage by virtue of its factor endowments.

Heckscher–Ohlin (H–O) Model of International Trade

The direction and patterns of virtual water trade should be predictable and in agreement with the Heckscher-Ohlin (H-O) model of trade. Developed by Eli Heckscher and Bertil Ohlin, the Heckscher-Ohlin (H-O) model builds on Ricardo's theory to predict patterns of trade and production based on the factor endowments of trading entities. Broadly, the model states that countries (or regions) will export products that require high quantities of abundant resources and import products that require high quantities of scarce resources. Thus, a capital-rich (and relatively labor-scarce) country would be expected to export capital-intensive products and import labor-intensive products or services and vice versa (IESC 2007; Antras 2007; Davis 2007). In the context of virtual water trade, this translates to water-rich regions exporting water-intensive products and vice versa.

Leontief Paradox

However, even in trade of goods and services, the H-O model has been found wanting in terms of empirical evidence to support its logic. In 1954, Prof. W.W. Leontief attempted to test the H-O model by studying trade patterns between countries. To his surprise, he found that the US, perhaps the most capital-abundant country in the world, exported labor-intensive commodities and imported capital-intensive commodities. This was seen to be in contradiction to the H-O model and came to be known as the Leontief paradox.

Linder Effect

Several economists have, ever since, tried to resolve this paradox. In 1961, Staffan Burenstam Linder proposed the Linder hypothesis as a possible resolution to the Leontief paradox. Linder argued that demand, rather than comparative advantage, is the key determinant of trade. According to him, countries (or entities) with similar demands will develop similar industries, irrespective of factor endowments; and that these countries would then trade with each other in similar but differentiated goods. For example, both the US and Germany are capital-rich economies with significant demand for capital goods such as cars. Rather than one country dominating the car industry (by virtue of factor-endowment based comparative advantage), both countries produce and trade different brands of cars between them. This Linder effect has also been observed in other subsequent examinations. However, it does not account for the entire pattern of world trade (see Linder 1961; Bergstrand 1990).

New Trade Theory

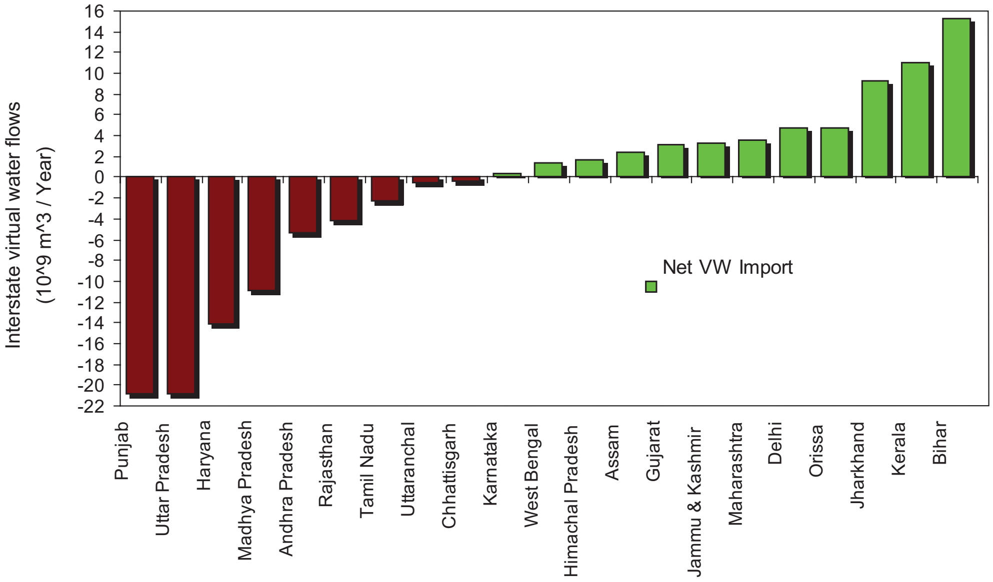
Similarly, proponents of the New Trade Theory (Paul Krugman, Robert Solow and others) argue that factors other than endowments determine trade. New trade theorists base international trade on imperfect competition and economies of scale—both of which are realistic but assumed away in the H-O model. Gains from increasing returns to scale at the entity level are understood intuitively but gains from industry-level scale economies (external economies of scale) often get ignored. Such gains are particularly important in the case of agriculture where the scale of production of an individual farmer is very small compared to the size of the market. However, several factors such as agricultural extension services, specialized machinery markets and fertilizer markets, marketing channels for outputs, etc., contribute significantly in determining where agricultural commodities are produced.

Interstate Virtual Water Trade in India: Quantum and Direction

Kampman (2007) estimated that the virtual water flow as a result of interstate crop trade in India is 106×10^9 m^3/yr or 13% of the total water use. This estimate covers virtual water flows as a result of trade in 16 primary crops which represent 87% of the total water use, 69% of the total production value and 86% of the total land use. The estimates do not include virtual water flows as a result of trade in fodder, milk and milk products. Verma (2007) estimated that, at the current level of production and consumption, milk and milk products are unlikely to significantly add to the interstate virtual water flows since India as a whole is milk-surplus and consumption levels in states that produce less milk are much below the prescribed standards for nutritional security. However, if we consider a scenario of nutritional security (where minimum nutritional standards are met in every state), we can expect interregional virtual water flows of around 40×10^9 m^3/yr. Under such a scenario, the interstate virtual water flows will be still higher since there would also be some interstate flows within each of the four regions (North, East, West and South).

Based on certain assumptions about interstate movements of agricultural products, Kampman (2007) estimated the mean annual import (or export) of virtual water between states (see Figure 2). According to these estimates, the Punjab,[3] Uttar Pradesh and Haryana are the largest exporters of virtual water while Bihar, Kerala, Gujarat, Maharashtra, Jharkhand and Orissa are the key importers. Aggregating the flows at the regional level, Kampman (2007) found that eastern India, India's wettest region and prone to annual floods, imports large quantities of virtual water not only from the north, west and south but also from the rest of the world (Figure 3).

Figure 2. Interstate virtual water flows (10^9 m^3/yr), as estimated by Kampman (2007).



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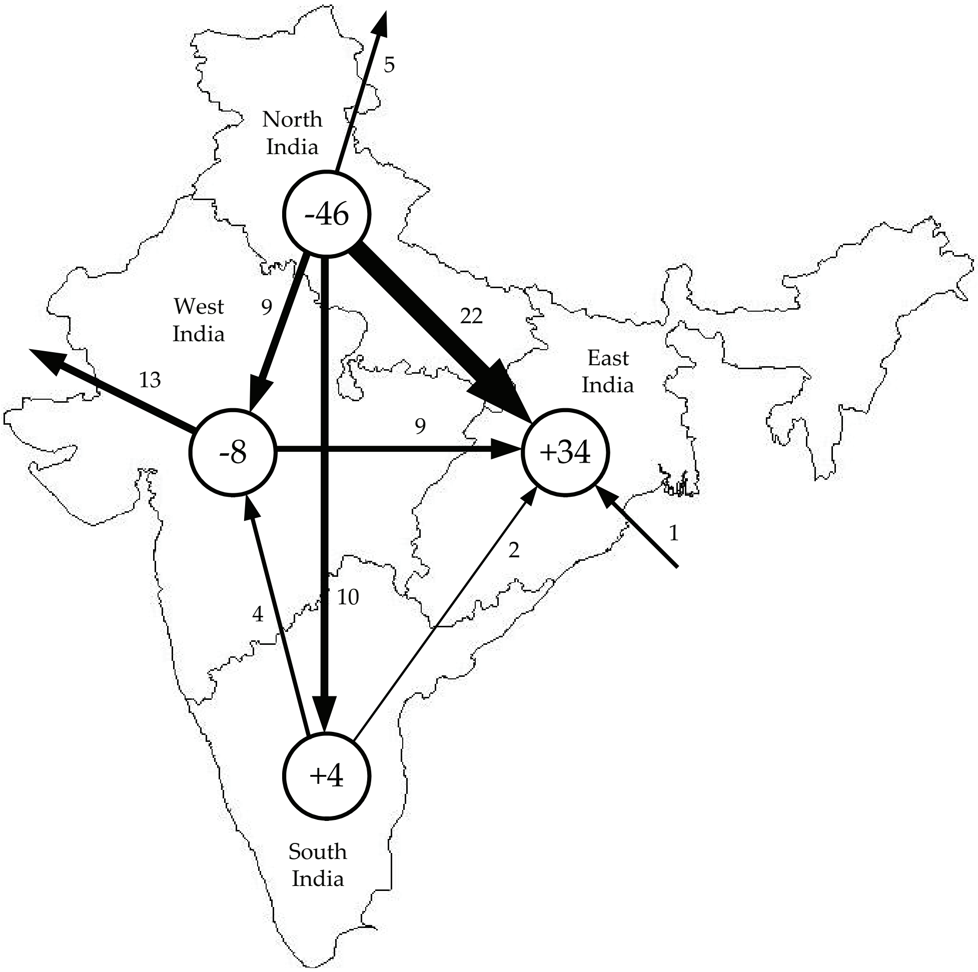
[3] In this paper by "Punjab" we mean the Indian Punjab.

Figure 3. Interregional virtual water flows (10^9 m^3/yr), as estimated by Kampman (2007).



The key virtual water importers—the eastern Indian states of Bihar, Jharkhand and Orissa—enjoy a comparative advantage over the key virtual water exporters—the northern states of Punjab, Uttar Pradesh and Haryana—if we look at the per capita water availability. The per capita water availability in all the three eastern Indian states is significantly higher than that in the northern states (see Table 1). Thus, we can see that the states which enjoy a natural comparative advantage (in terms of water endowments) actually have a net import of virtual water.

The NRLP proposes to transfer excess floodwater from the eastern states such as Assam, Bihar, West Bengal, Chattisgarh, etc., to the water-scarce regions which produce the bulk of the food thereby ensuring India's national food security. However, the proponents of the virtual water trade argument have repeatedly claimed that such a transfer would only accentuate what they term as the "perverse" direction of virtual water trade in India. They argue that going by theories of trade, water-rich states in eastern India should be producing much of India's food requirements and exporting food grains to the water-scarce states. However, as we can also see from the figures above, at present, the reverse is happening. Rather than having surplus produce to export to relatively water-scarce regions, the deficit in eastern India is so high that it even requires imports from outside India.

Table 1. Virtual water trade balances and water endowment.

States	Per capita water resources					Net virtual water import
	Green (G)	Blue (B)			Total (B+G)	
		Internal	External	Total		
	m^3/capita/yr					10^9 m^3/yr
Major virtual water exporters						
Punjab	1,102	193	2,260	2,452	3,554	20.9
Uttar Pradesh	863	575	1,485	2,059	2,922	-20.8
Haryana	1,121	391	663	1,055	2,176	-14.1
Major virtual water importers						
Bihar	789	628	5,482	6,109	6,898	15.3
Jharkhand	2,082	1,970	528	2,498	4,580	9.3
Orissa	3,446	3,079	2,185	5,264	8,710	4.8

Critics of the NRLP argue that such a “perverse” direction is the result of food and agriculture policies that have been biased in favor of states like the Punjab and Haryana where farmers receive highly subsidized agricultural inputs (including water for irrigation) and are assured high prices for the wheat and rice they produce through the procurement policies of the Food Corporation of India (FCI). The proponents of the virtual water trade argument contend that if these policies were to be revised in favor of the wetter states, the so-called “perverse” direction of food trade would get “rationalized” and the water-rich states would no longer have to import virtual water from water-scarce states.

Determinants of Interstate Virtual Water Trade in India

Why do water-rich states import even more water (in virtual form) from relatively water-scarce states? In order to test the relationship between the water resources endowments of states and their behavior in the virtual water trade arena we checked whether the type of water endowment mattered. Figures 4 (a) to 4 (d) plot net virtual water imports (or exports) against per capita green water availability: (a) per capita internal blue water availability, (b) per capita total blue water availability, (c) per capita total [internal blue + external blue + (internal) green] water availability, and (d) as estimated by Kampman (2007). We use Figure 2 as a starting point but omit states with net inflow or outflow less than 2×10^9 m^3/yr, given the approximate nature of Kampman’s (2007) estimates.

If water endowments were to influence virtual water trade as hypothesized by the virtual water theorists, we would expect that as we move along the plots from left to right, moving from the largest exporters to the largest importers, the water resource endowments would show a declining trend. The four trend lines do not depict strong correlations (R^2 in the range of 0.004 to 0.060) or point to any such trend. Thus clearly, in the case of interstate virtual water flows, better water endowments do not lead to higher virtual water exports.

International trade in agricultural commodities depends on a lot more factors than differences in water scarcity in the trading nations, such as differences in availability of land, labor, knowledge and capital and differences in economic productivities in various sectors. Also the existence of domestic subsidies, export subsidies or import taxes in the trading nations may influence the trade pattern. As a consequence, international virtual water transfers cannot be explained at all, or can only be partially explained on the basis of relative water abundances or shortages (De Fraiture et al. 2004; Wichelns 2004). Yang et al. (2003) demonstrated that it was only below a certain threshold in water availability that an inverse relationship can be established between a country's cereal import and its per capita renewable water resources. As shown here, trade of agricultural commodities between Indian states is not governed by water-scarcity differences between the states.

Figure 4a. Virtual water trade and per capita green water availability (R2 = 0.004). as estimated by Kampman (2007).

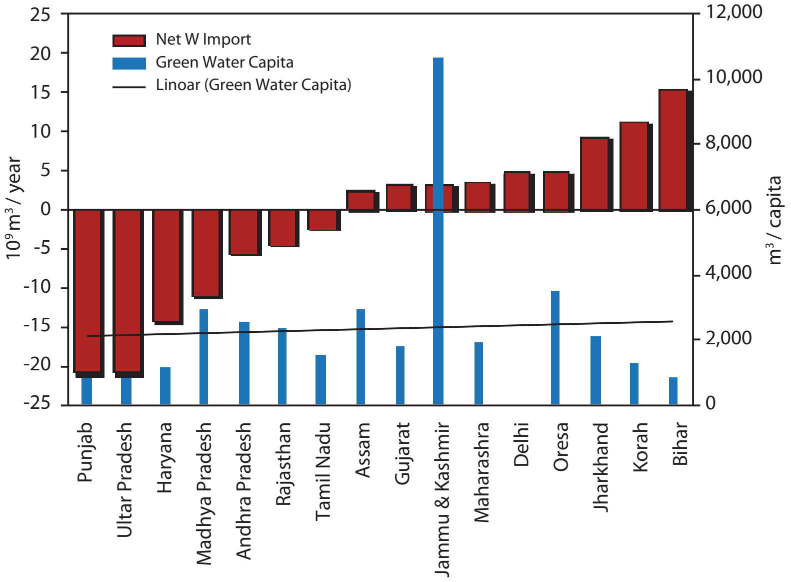


Figure 4b. Virtual water trade and per internal blue water availability (R2 = 0.058). as estimated by Kampman (2007).

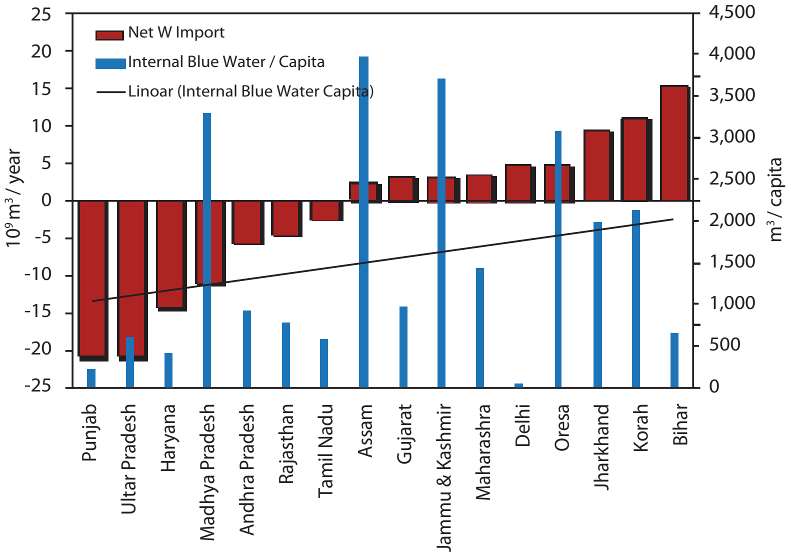


Figure 4c. Virtual water trade and per capita total blue water availability (R2 = 0.004), as estimated by Kampman (2007).

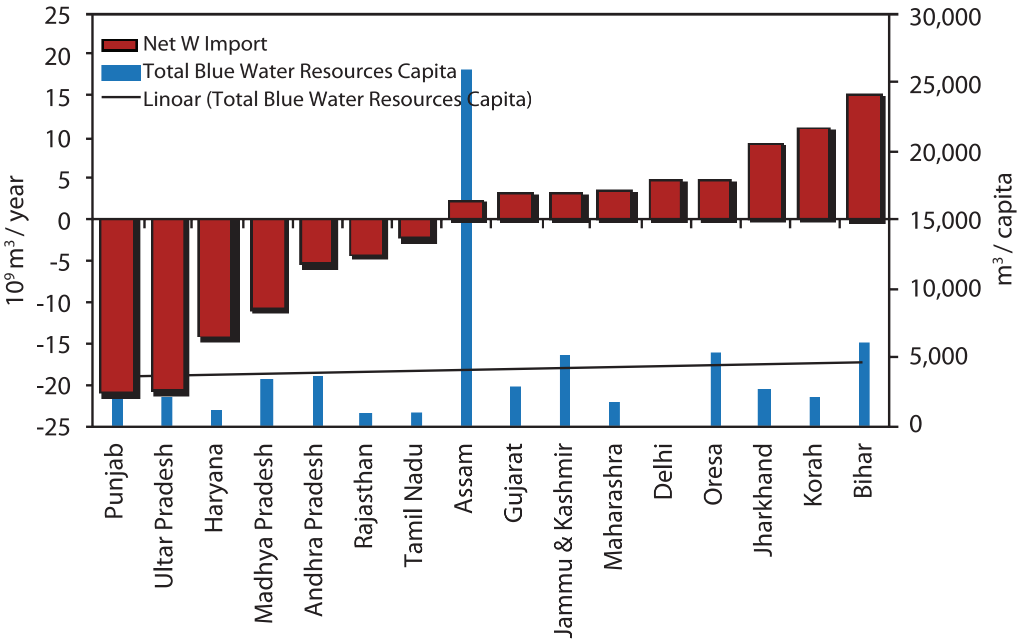
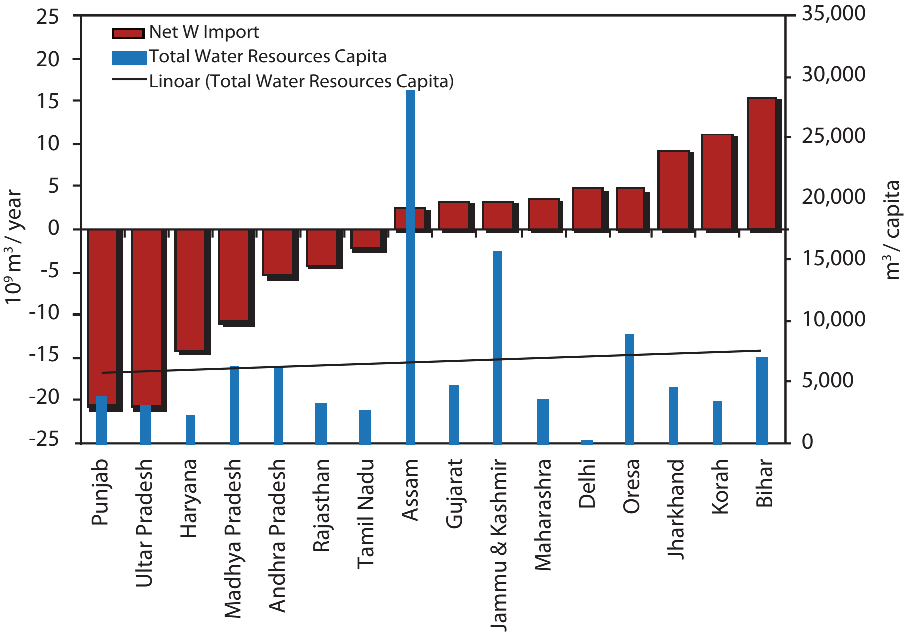


Figure 4d. Virtual water trade and per capita total resource water availability (R2 = 0.006), as estimated by Kampman (2007).



Source: Verma et al. 2009.

Figure 5. Virtual water trade, as estimated by kampman (2007) and per capita Gross Cropped Area (GCA) ($R^2 = 0.39$). Data Source : Ministry of Agriculture, Goverment of India; accessed from www.indiastat.com.

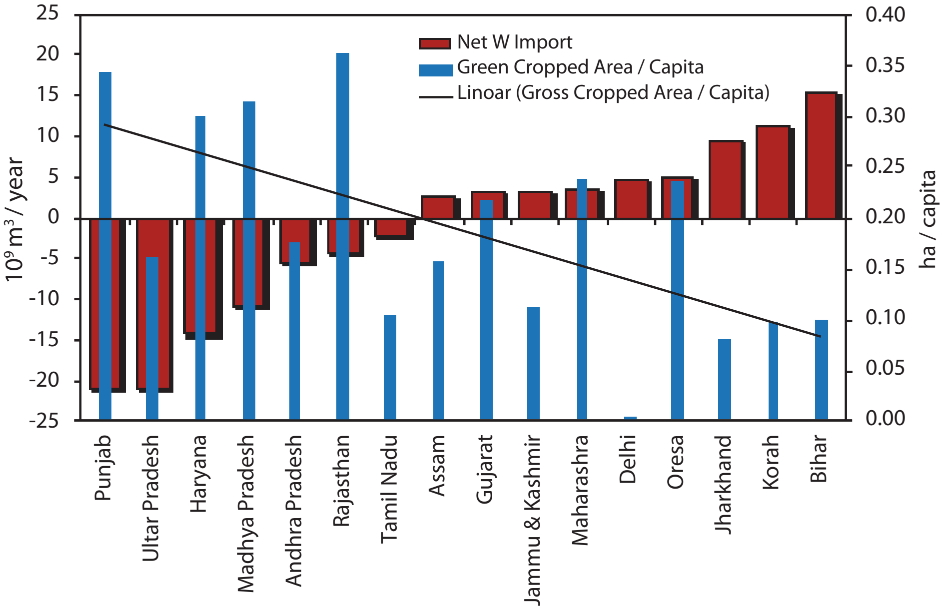
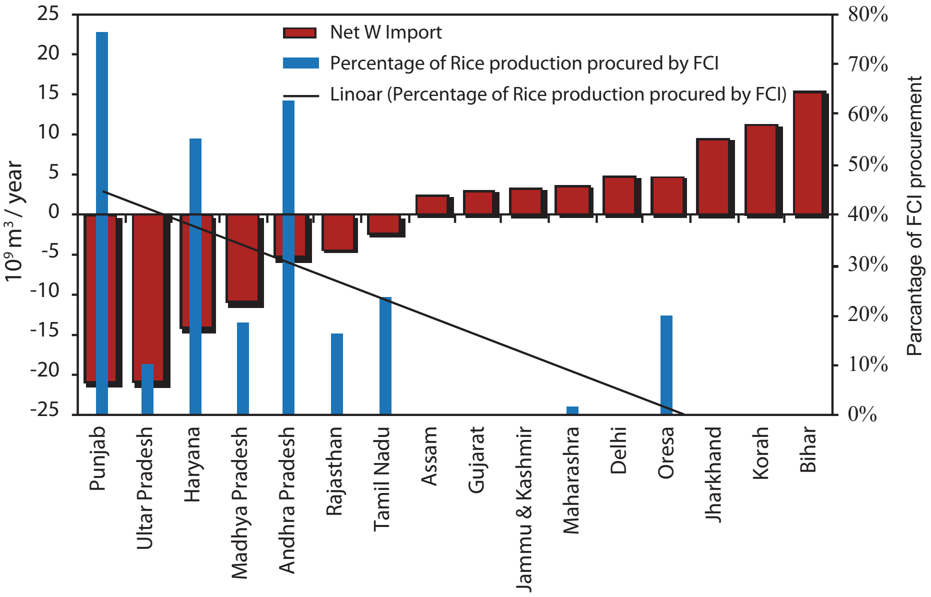


Figure 6. Virtual water trade, as per Kampman (2007) and percentage of rice production procured by Food Corporation of India (FCI) (R2 = 0.47). *Data Source:* Ministry of Agriculture, Goverment of India; accessed from www.indiastat.com.



Source: Verma et al. 2009.

If it is not water endowment that determines the direction of virtual water flow, then what does? In a recent paper analyzing data for 146 countries across the globe, Kumar and Singh (2005) have argued that a country's virtual water surplus or deficit is not determined by its water situation. They concluded that no correlation exists between relative water availability in a country and virtual water trade or the volume of water embedded in the food and food products traded. Several water-rich countries including Japan, Portugal and Indonesia have recorded high net virtual water imports.

Further analysis of 131 countries in the same paper showed that "access to arable land" can be a key driver of virtual water trade. We test this "access to arable land" hypothesis using per capita gross cropped area data for the Indian states (Figure 5). As can be seen from Figure 5, per capita gross cropped area does seem to assert a strong influence on net virtual water exports. The correlation coefficient ($R^2 = 0.39$) is much higher than that related to water endowment.

In our analysis of high food exports from the northern Indian states, it was suggested that "access to secure markets" could be a key determinant of why the Punjab continues to produce food grains. We therefore also test "access to secure markets" across virtual water importing and exporting states by using the proxy variable of 'percentage of rice production procured by the Food Corporation of India' (Figure 6). We find that this percentage correlates well with net virtual water exports ($R^2 = 0.47$). Thus we see that while the correlation between water endowments and virtual water surplus/deficit is very weak, access to arable land and access to secure markets are much more strongly correlated with virtual water exports.

Discussion: Why H-O Does Not Work for H_2O?

If the H-O model of international trade was able to explain the quantum and direction of trade, we would have expected water endowments to be strongly and positively correlated with a region's virtual water exports. However, our estimates of interstate virtual water trade clearly do not match with such a pattern. One of the reasons for this could be the method Kampman (2007) applied for estimating interstate trade. Kampman assumed that trade (import or export) is equal to the difference between production and consumption within a state. Thus, only surplus states export and only deficit states import. Such an estimation procedure implicitly assumes that all traded agricultural goods are undifferentiated commodities. But we know that products such as basmati rice, branded dairy products and other differentiated (or branded) agricultural commodities negate this assumption. However, in comparison to the total volume of virtual water traded, the proportion of virtual water embedded in branded products is perhaps small.

Another reason that the H-O model fails to apply is that it requires pre-trade resource prices to be in relation to resource endowments. In the case of water, this does not happen, especially at the farm level. Farmers in water-rich states such as Bihar face a much steeper price for using water for irrigation compared to water-scarce states like the Punjab. This can be attributed to the public policy biases in favor of regions such as the Punjab. Thus while a region might be facing physical water scarcity, the farmers do not face any economic scarcity while the reverse is true for wetter regions.

Thus, though intuitively appealing as a concept, the idea of using virtual water as a tool for water saving, or as an alternative to physical water transfers, has limited applicability in the current scenario. Virtual water trade theorists have often implicitly and erroneously assumed that water-abundant countries (or regions) necessarily enjoy comparative advantage in the production of water-intensive commodities. The patterns of interstate virtual water trade in India and global food trade trends discussed by De Fraiture et al. (2004) show that water endowments alone are unable to explain the direction and magnitude of trade. The Leontief paradox holds as much in the case of virtual water trade as it does for other goods. The implicit assumption behind measuring every commodity by its virtual water content is that water is the most critical and scarcest resource input. However, this assumption does not always hold. There are several key inputs that go into the production of food and these other 'factors of production' might tilt the balance of decisions against the logic of virtual water which dictates water saving as the sole criterion.

Thus, the H-O model will work to efficiently allocate water resources if and only if they constitute the most critical resource in the production process. If, on the other hand, another resource such as land becomes the critical constraint, efficient allocation will optimize land use and not water use. By importing food grains from a land-rich state, a land-scarce region is economizing on its land use. Following the virtual water trade logic, this can be termed as *virtual land trade* (see Würtenberger et al. 2006). A land-scarce region (such as Bihar) would import crops from regions where land productivity is higher (for instance, the Punjab). In order to produce the same amount of food as in the Punjab, Bihar would have to employ more land than Punjab (Aggarwal et al. 2000). If, and as long as, land is the critical constraining resource, Bihar would like to economize on its land use, even at the cost of inefficient or incomplete utilization of its abundant water resources.

Conclusions and Implications for India's River Linking Project

The mean annual interstate virtual water trade in India has been estimated to be 106×10^9 m^3/yr for the years 1997–2001 (Kampman 2007). While these estimates are neither precise nor comprehensive (for instance, Kampman's estimates do not include virtual water trade through trade in milk and milk products), they do illustrate that the quantum of interstate virtual water trade is comparable to the proposed interbasin water transfers proposed by the Government of India under the NRLP (178×10^9 m^3/yr). Significantly, the estimates also show that the direction of virtual water trade runs opposite to the proposed physical transfers. While physical water transfers are proposed from 'surplus' to 'deficit' basins, interstate virtual water flows move from water-scarce to water-rich regions.

The existing pattern of virtual water trade is exacerbating scarcities in already water-scarce regions and our analysis has shown that rather than being dictated by water endowments, trade patterns are influenced by factors such as per capita availability of arable land and, more importantly, by biases in food and agriculture policies of the Government of India as indicated by the FCI's procurement patterns. Given that the desperation of the 1960s and 1970s with respect to national food security no longer persists, there is a strong case for reversing this trend through changes in food procurement and input subsidy policies.

According to international trade theory, there are five basic reasons why trade takes place between two entities: (1) differences in technological abilities, as explained by the Ricardian model of comparative advantage; (2) differences in resource endowments, as explained by the H-O model; (3) differences in demand, which partly explain trade between surplus entities, as explained by the Linder effect; (4) existence of economies of scale, as enumerated by the new trade theory; and (5) existence of government policies which might create new comparative advantages and disadvantages that are different from natural advantages and disadvantages (Suranovic 2007).

Much of the literature on virtual water trade, just as the H-O Model of international trade, focuses almost entirely on differences caused by factor (in this case, water) endowments or on the Ricardian logic of trade. However, this paper argues that in order to have a comprehensive understanding of the behavior of agents in trade, all other reasons including endowments of non-water factors of production (such as land) need to be taken into consideration. Further, it is *economic* rather than *physical* water scarcity/abundance that influences trade and economic scarcity as defined by government policies on agricultural inputs, extension services, access to assured markets and minimum support prices.

Finally, while our analysis based on estimates of trade balances at the state level provides a conceptual picture of the conflict between the two alternatives of virtual water trade and physical interbasin water transfers, the same can more accurately be evaluated by carrying out an empirical study of the potential of virtual water trade in a particular proposed river link. Three of the 30 odd links proposed under the NRLP are independent links and the first one most likely to be implemented is the Ken-Betwa link between two adjoining subbasins in central India. Carrying out such an analysis at that scale with data on actual (as opposed to estimated) trade and better estimates of water resources in the donor and recipient basins will be a useful exercise to further our understanding of virtual and physical transfers across river basins, and their possible trade-offs.

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Assessing Net Economic Gains from Domestic and Industrial Water Supply: Cases from NRLP Schemes

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Summary

This paper attempts to identify and evolve a method for valuing and estimating the net gains from domestic and industrial water supply from the interbasin transfer schemes contemplated in the National River Link Project (NRLP). An existing interbasin transfer (IBT) scheme, namely Indira Gandhi Nahar Project (IGNP) and a proposed IBT scheme namely Polavaram-Vijaywada (PV) Link Canal were chosen for detailed analyses. Secondary data were used for identifying the region and the populations that benefited from the schemes. Economic gains arising out of water supply to the actual or potentially benefited areas were estimated. The estimation involved assessment of current costs incurred by the people in the area, in terms of both paid-out costs and time spent in fetching water. The saving in time was valued at market wage rates prevalent in the area and paid-out costs were assessed in terms of current market prices, ignoring the administered prices involved. The gains to urban populations were assessed by estimating the reduction in energy costs incurred by municipal authorities in undertaking the supply. Amortized capital costs for putting necessary hardware for distributing water from the IBT schemes as well as operation and maintenance (O&M) costs of running these schemes were netted from the gains to obtain the figures for net economic gains. More indirect benefits such as reduced drudgery or improved educational performance as well as reduced health expenditure were recognized but were all ignored to ensure greater robustness in the estimates. Only net gains to the society were considered and hence gains arising out of creation of industrial estates within the commands were ignored since similar gains could also be obtained by locating these estates elsewhere. The net economic gains are seen to depend on both demographic features of the region and its ecology. Desert-like conditions of the IGNP-benefited areas tend to make the gains from domestic water supply schemes large, while similar gains in the Polavaram-Vijaywada areas are smaller. The net economic gains are of a significant order and would seem to indicate that, at least insofar as the dry areas of the country are concerned, these can perhaps exceed the gains due to increased agricultural production and hence could perhaps justify the creation of the schemes by themselves.

Introduction

The proposed project to build 37 links between the Himalayan and peninsular rivers in the country, together called the National River Link Project (NRLP), is a huge program, which would change the face of the countryside. It envisages transferring of some 178 billion cubic meters (Bm^3) of water through these links and making large quantities of water available for irrigation and other uses. The project does envisage benefits on three fronts: bringing additional areas under irrigation for producing the food that would be required to feed an estimated population of 1,580 million in the country; producing a huge amount of electricity by installing hydropower projects on the Himalayan rivers; building infrastructures useful for accomplishing water transfer, and delivering the supply of water for domestic and industrial uses in water-starved southern and western peninsular regions. Much discourse about the project revolves around the appropriateness of providing such extra irrigation through the link schemes while significant attention has also been given to aspects of environmental impacts and seismic stability of the structures on the Himalayan rivers. We believe that huge benefits of the project are in the supply of drinking water to literally millions of households and also in enabling industrial activity to take place in areas starved of water. We suggest that the economic benefits accruing from these end uses are likely to be far more significant than the irrigation benefits, particularly as there may be few alternatives to large-scale IBTs for supporting dozens of thickly populated and growing urban centers.

According to recent experience from several large dams in the country (e.g., Narmada Dam, Jayakwadi Dam on the Godavari and scores of smaller projects elsewhere), they may be economically justified by looking at agricultural production they have enabled and the electricity produced on these structures. Their contribution is most striking in enabling the concerned state governments to augment and stabilize water supply for domestic purposes to cities, towns and villages and in supplying water to industrial estates. The Jayakwadi, for instance, not only sustains cities of Aurangabad and Jalna and several smaller townships by supplying drinking water but has enabled the Walunj and other industrial estates to flourish. The case of the Narmada Dam is even more pertinent. The project has not started irrigating more than a fraction of its proposed command but already the project has enabled the state government to augment and strengthen the water supply in over 200 cities and towns and in a few thousand villages. In fact, the Government of Gujarat has been proud in proclaiming its achievements in solving the drinking water crisis facing the difficult Saurashtra and Kutch areas. The case of many other projects originally designed as irrigation schemes is similar: the Pench project has turned out to be a boon in supporting the 3 million strong Najaur City; but for the Upper Wardha project, the neighboring Amravati District would have continued to face tough problems; the Nagarjuna-Sagar Dam gives water through the Telugu Ganga canal to Chennai City; Ujani supports Solapur and soon Godavari water will be taken to support Hyderbad-Secunderabad.

The premise of this exercise is that irrespective of the planning objectives of the projects and the economic rationale on which they are justified, the various projects in the NRLP will, in fact, be used, whether directly or indirectly (through the substitution route), to a significant extent to address the question of supplying drinking water to populations facing the threat of unreliable water supply and to augment water supply to industrial estates and units which would find it difficult to carry out their industrial activities without water supply. The exercise looks at one existing instance of interbasin transfer of water (namely the IGNP, from the Indus to the Luni and other basins) and one proposed Polavaram-Vijaywada (PV) Link which would be one of the elements of the NRLP design.[1]

The exercise is aimed at arriving at a broadly acceptable estimate of the (actual in case of IGNP or likely in the second case) net economic gain resulting from the use of water from these projects for domestic and industrial purposes. The tasks involved in the exercise include identifying the benefits in the industrial and domestic water supply that can be attributed to these projects, estimating the quantum of these gains and valuing them.

The Study Area

The tasks of identifying attributive gains relate to identifying geographic areas covering cities, towns, villages and industrial estates to which the water from these projects actually flows or will actually flow. For this purpose, the use of maps and other secondary materials from concerned government offices is resorted to. The task of estimating the volume of gain consists of identifying the current and potential water needs of geographic areas where the gains due to water can be attributed to these schemes. This is an exercise in the projection of demographic changes and possibly industrial growth. The former is relatively simple and in conjunction with the work done under NRLP on demographic changes last year, it can be accomplished without much effort. The latter is speculative since the industrial growth in a region is a determinant of several factors, one of which is uninterrupted and adequate supply of water. Valuation remains an issue and will be discussed later.

Indira Gandhi Nahar Pariyojana

The Indira Gandhi Nahar Pariyojana (IGNP) with a command area of 1.543 million hectares (Mha) is the largest irrigation and drinking water project in northwestern Rajasthan. The project was taken up in three stages. The first stage has already been completed, the second was recently completed and the third is under execution. Stage II area of IGNP starts from Pugal and comprises the main canal from 620 RD to 1458 RD. The main canal gets water from the Sutlej River in Punjab through a feeder canal.

The climate of the region is arid with an average annual rainfall of about 200-250 mm. The temperature ranges from freezing point in winter to above 50° C in summer. The area covered by the IGNP consists of sandy undulating plains with various types of low-to-medium sand dunes. The thickness of sand cover varies from a few centimeters to 200 meters (m). The top aeolian soils have high permeability but the underlying sediments, comprising silty clay and *kankar*, have low permeability. Prior to introduction of the canal irrigation, only rain-fed agriculture was practiced. But the introduction of canal irrigation has changed the cultural practices. Groundwater was also not generally available before the introduction of this canal system. Barring a few sweet water locations along buried channels, groundwater where present, was deep and saline. The main cause of the rise in water tables in IGNP Stage-

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[1] The Government of Andhra Pradesh (GoAP) has proposed the Pollavaram Dam and the link canal to Vijaywada irrespective of the realization of the NRLP design. However, the same dam would be a link between the Mahanadi-Godavari scheme on the one hand and Godavari-Krishna (Pollavaram-Vijaywada) Link on the other.

II command is the presence of a hard pan at shallow depths. This pan restricts the downward movement of the groundwater, resulting in the formation of perched water tables.

The main soil types of the study area are deep and calcareous flood plain soils and sand dunes. The geology of the area is marked by aeolian sand and alluvium of quaternary age forming extensive sandy plains. Alluvium is mostly fluvial in origin and comprises unconsolidated to loosely consolidated sediments, consisting of an alternate sequence of sand, silt and clay with frequent lens of silty clays and kankar with occasional gravel horizons. Groundwater occurs in these alluvial sediments under water-table conditions. Groundwater is generally saline in most parts of the study area. The important components of groundwater recharge in the area are the IGNP canal system and their distributaries, Ghaggar Diversion Channel (constructed to divert the floodwater of Ghaggar River to inter-dunal depressions) and inter-dunal depressions south of Suratgarh. A substantial part of recharge is contributed by return flow of irrigation water and some by annual precipitation. The groundwater level in the area has been rising since the commencement of canal irrigation leading to waterlogging in the area. This high rise in groundwater levels has led to systematic monitoring of groundwater levels from the year 1981-82.

Polavaram-Vijaywada Link Canal Area

Andhra Pradesh is bestowed with 108 Bm^3 of water from groundwater, local and interstate rivers out of which only 78 Bm^3 are usable (GoAP 2003 b) . The present total use is about 62.3 Bm^3 which are expected to reach 113 Bm^3 by 2025 assuming that 3.5, 108, 1.4 and 0.1 Bm^3 are required for drinking water, irrigation, industries and for power generation, respectively, Hence, by 2025, the total water demand would have crossed the total availability.

Besides, about 36% of rural habitations and 72% of urban bodies still do not have adequate drinking water facilities. The key water challenge in the state is increasing demand for industrial and domestic water, which will have to be met from the present allocation to the agriculture sector.

Long-distance interbasin transfer of water from water-surplus basins to water-deficit basins has been mooted in India in order to reduce the imbalance in the water availability among various regions. A National Perspective Plan (NPP) was formulated in 1980 by the Union Ministry of Irrigation (now Ministry of Water Resources) and the Central Water Commission, identifying a number of interbasin water transfer links in respect of both the peninsular and the Himalayan rivers of the country. The Peninsular Rivers Development and the Himalayan Rivers Development components put together were expected to create an additional irrigation potential of 35 Mha besides hydropower potential and other benefits.

The interlinking of Mahanadi–Godavari-Krishna-Pennar-Cauvery is one of the four parts of the Peninsular Rivers Development Component of the NPP. Amongst the peninsular rivers, the Mahanadi and the Godavari have sizeable surpluses after meeting the existing and projected requirements within the basins. It is, therefore, proposed to divert the surplus water of the Mahanadi and the Godavari to the water-short river basins: the Krishna, the Pennar and the Cauvery. Three water transfer links have been proposed, connecting Godavari to Krishna, forming part of the interlinking. They are: (i) Inchampalli-Nagarjunasagar, (ii) Inchampalli-Pulichintala, and (iii) Polavaram-Vijayawada. This report deals with the feasibility of the third link, i.e., diversion of a part of the surplus Godavari water from the proposed Polavaram Reservoir to the Prakasam Barrage on the Krishna River through the Godavari (Polavaram).

The National Water Development Agency (NWDA) has been carrying out water balance and other studies on a scientific and realistic basis for optimum utilization of water resources for preparing feasibility reports and thus to give concrete shape to the proposals of the NPP. The objective of preparing the feasibility report is mainly to facilitate firming up of the proposals and for discussions among the concerned states to arrive at broad agreements on the quantum of diversions and utilizations of water, sharing of cost and benefits, etc. This report has been prepared keeping in view the various comments offered by the governments of Andhra Pradesh, Madhya Pradesh and Karnataka on the topo-sheet study and pre-feasibility study of the Godavari (Polavaram)-Krishna (Vijayawada) Link project.

The Godavari Water Disputes Tribunal (GWDT) award stipulates, among other provisions, transfer of 2,265 Mm^3 of water from Godavari at Polavaram to Krishna above the Prakasam Barrage at Vijayawada, thereby displacing the discharges from Nagarjunasagar project for the Krishna Delta, and thus enabling the use of the above quantity for projects upstream of Nagarjunasagar. However, considering the possible full development of irrigation in the basin and projected in-basin uses for domestic and industrial requirements up to the year 2025 and also considering the proposed transfer of 6,500 Mm^3 from Mahanadi to Godavari through the Mahanadi (Manibhadra)-Godavari (Dowlaiswaram) Link, NWDA by simulation studies, has assessed that it is possible to transfer an additional quantity of 1,236 Mm^3 through the proposed Polavaram-Vijayawada Link Canal from Godavari to Krishna. An equal quantity of water can be made available for possible use in the water-short upper regions of the Krishna Basin by way of substitution. The Polavaram project has been formulated by the Government of Andhra Pradesh for the utilization of Godavari water for irrigation and other benefits by creating a reservoir and canal systems at Polavaram about 42 km upstream of the existing Godavari Barrage at Dowlaiswaram near Rajamundry. The Polavaram project will also cater to the transfer of 2,265 Mm^3 of Godavari water to Krishna as agreed to by the states concerned and reflected in the GWDT award. A detailed project report on the Polavaram project has been prepared by the Government of Andhra Pradesh. The project proposals include the construction of an earth-cum-rockfill dam across Godavari at Polavaram for creating a reservoir of 2,130 Mm^3 live storage capacity; a Left Main Canal with a capacity of 250 m^3/sec. for providing irrigation to a culturable command area (CCA) of 1,74,978 ha and supplying 664 Mm^3 to the steel plant and other industries of Visakhapatnam; and a Right Main Canal with a capacity of 453 m^3/sec. for providing irrigation to a CCA of 139,740 ha besides transferring 2,265 Mm^3 of Godavari water to Krishna. The project also includes a hydropower component for generating 60 MW of firm power with an installed capacity of 720 MW.

The Polavaram-Vijayawada Link Canal now proposed by NWDA and detailed in this feasibility report will be incorporated in the Polavaram project of Andhra Pradesh. The link canal will replace the Right Main Canal of the Polavaram project. In fact, the alignment of the link canal has been proposed to be the same as that of the Right Main Canal as proposed by the State Government.

The Godavari (Polavaram)-Krishna (Vijayawada) Link Canal takes off from the right bank of Godavari at the proposed Polavaram Reservoir. The canal, after traversing 174 km, falls into the Budameru River (which drains into the Kolleru Lake) at a point upstream of the Velagaleru regulator. From the regulator, the canal water is let into the existing Budameru Diversion Channel that, after traversing 12 km, joins the Krishna River at about 8 km upstream of the existing Prakasam Barrage at Vijayawada. Diversion of 5,325 Mm^3 of water is envisaged through the canal. This will cater to (i) a transfer of 2,265 Mm^3 to the Krishna Delta as committed under the GWDT award, (ii) an en-route irrigation requirement of 1,402 Mm^3, (iii) en-route domestic and industrial requirements of 162 Mm^3, and (iv) transmission losses of 260 Mm^3. The remaining 1,236 Mm^3 of water will be utilized for stabilizing the existing ayacut under the Krishna Delta. With 1,402 Mm^3 of water available for en-route irrigation, an area of 139,740 ha (CCA) will be benefited with 150% intensity of irrigation. The entire canal and the command areas lie in Andhra Pradesh.

The total length of the link canal from Polavaram to Budameru will be 174 km. The canal will pass through West Godavari and Krishna districts of Andhra Pradesh. The design discharge at the head of the canal is 405.12 m^3/sec. The canal will be trapezoidal and lined throughout its length. The bed width will be 68.5 m and full supply depth 4.9 m. The bed slope will be 1: 20,000. The link canal is proposed to be operated throughout the year.

The total cost of the Polavaram-Vijayawada Link project including the cost of command area development, but excluding the apportioned cost of head works, i.e., Polavaram Dam and appurtenant works, is estimated to be Rs 14,839.1 million at the 1994-95 price level. The net value of annual benefits from irrigation in the en-route command due to the project works out to Rs 2,011 million against the annual cost of Rs 1,646.274 million. Thus, the benefit:cost ratio works out to 1.22.

The structures including the main link canal pass through the districts of East and West Godavari and Krishna. These two districts have coastal alluvial soils in the east of the canal and lateritic soils on the western parts of the canal. The western parts tend to be on a higher elevation and water from the canal will not flow to them under gravity. The deltaic regions are agriculturally very rich with crops such as sugarcane, paddy, banana and oil palm. Tobacco is grown extensively on both the eastern and the western land masses of the canal. The Koleru Lake widely known for its fish production lies to the east of the canal. The region has a tropical humid climate.

Drinking Water Supply

Situation of Drinking Water in IGNP

There is widespread scarcity of potable water in the northwestern part of the state, which is the area under IGNP. In the first place, groundwater is generally saline and unfit for human consumption. Second, the existing surface water resources are not adequate or dependable. The canal has become in its true sense a "life line" for this area. When the first revised estimates for Stage-II of IGNP were sanctioned in May 1972, the available quantity of water was to be used for agricultural purposes besides meeting the drinking water requirements of the villages and *abadis* located in the command areas. Subsequently, requirements for water for drinking and industrial purposes went on increasing. A provision of 1,073 Mm^3 was kept for nonagricultural purposes in the 1984 revised estimate of the project. The Public Health Engineering Department (PHED), vested with the task of provision of drinking water, asked for more reservation of water for drinking and industrial activities in the command area on the basis of expected population rise in the following two decades.

The PHED supplies, on average, 1,344 million liters of water a day. Surface water contributes 604 million liters (45% of the total), and groundwater the remaining 740 million liters for Rajasthan (Tables 1 and 2).

Table 1. Population with drinking water facilities in Rajasthan.

District	FC	FC (%)	NC	NC (%)	PC	PC (%)	Grand total
Barmer	106,478	5.9	1,711,762	94.1	168	0.0	1,818,408
Bikaner	568,995	31.3	356,354	19.6	336,705	18.5	1,262,054
Churu	508,046	27.9	404,239	22.2	294,065	16.2	1,206,350
Ganganagar	1,077,473	59.3	127,223	7.0	140,490	7.7	1,345,186
Hanumangadh	747,088	41.1	35,583	2.0	428,425	23.6	1,211,096
Jaisalmer	50,334	2.8	355,074	19.5	26,448	1.5	431,856
Jhunjhanu	721,333	39.7	547,232	30.1	256,328	14.1	1,524,893
Jodhpur	41,567	2.3	1,640,413	90.2	231,718	12.7	1,913,698
Najaur	118,436	6.5	2,116,865	116.4	58,816	3.2	2,294,117
Sikar	519,198	28.6	786,928	43.3	509,124	28.0	1,815,250

Notes: FC=fully covered; NC= not covered; PC=partially covered.
Source: National Habitation Survey 2003, (GoI 2004).

Table 2. Sources of drinking water supply for the urban population.

Source of supply	No. of towns and cities	Quantity supplied	
		Million liters/day	Mm^3/yr
Surface water	40	604	220.5
Groundwater	151	740	270.1
Surface water and groundwater	31		
Total	222	1,344	490.5

Source: Report of the Expert Committee on Integrated Development of Water Resources, June 2005 (GoR 2005)

It is being proposed to provide water from IGNP not only for the project area but also for cities and villages located outside the command area. At present, IGNP water is being supplied to villages and towns partly or fully in eight districts. Two more districts will be added. Ultimately, a population of about 20 million located in 24 cities/towns and 5,300 villages/settlements would draw drinking water supplies form this canal by the year 2045 (GoR 2002).

Drinking Water Situation in the Polavaram-Vijayawada (PV) Link Canal

Sources of drinking water in the areas of PV Link canal are the main groundwater-based. Vishakhapattanam City slated to be among the main beneficiaries of the link in terms of supply of water for domestic and industrial applications (Table 3). At present, out of a total 65.12 Bm^3 water use, drinking water supply is 0.59 and industrial water use is 0.28 Bm^3, while irrigation receives the lion's share of 64.21 Bm^3 (GoAP 2003 b). There are several issues such as inequality in distribution of water supply in rural as well as urban areas, deterioration of water quality due to municipal/domestic, industrial and agricultural pollution, pricing of water, competing interests in the use and management of water and more efficient use of water in all the sectors.

Table 3. Drinking water in the PV Link canal area.

District	Mandalam	FC	FC (%)	NC	NC (%)	PC	PC (%)	Grand total
East Godavari	Amalapuram	36	26	1	1	102	73	139
	Biccavolu	3	17		0	15	83	18
	Peddapuram	7	28		0	18	72	25
	Seethanagaram	22	92		0	2	8	24
Krishna	Nuzvid	28	56	2	4	20	40	50
Vizag	Anakapalle	49	46	5	5	52	49	106
	Narsipatnam	8	17	4	9	35	74	47
West Godavari	Pedavegi		0		0	55	100	55
	Tadepalligudem	23	61	1	3	14	37	38

Notes: FC=fully covered; NC= not covered; PC=partially covered.

Source: National Habitation Survey 2003, Status of Drinking Water Supply, GoI 2004.

According to the Public Health and Municipal Engineering Department of the Government of Andhra Pradesh, only 33 out of 117 municipal bodies are being supplied with adequate water. An average supply of only 48 liters per capita per day (lpcd) could be achieved against the standards of 140 lpcd. Out of the 69,732 rural population in the state-protected area, water supply has been provided to only 44,951, and the remaining population is yet to be supplied with water. Nearly 75% of the rural drinking water requirement is met using groundwater, which is around 800 Mm^3 and likely to be 876 Mm^3 by the year 2020 (Table 4). Already, a population of more than 21,000 is affected with poor-quality groundwater (Panchayati Raj Rural Development Department RWS).

Table 4. Water requirement estimates of different sectors (Bm^3).

Year	Drinking water	Balance left for irrigation	Water for industries	Water for power	Total development
Present	0.59	64.21	0.28	0.03	65.12
2020	3.45	67.00	1.00	0.05	71.50
2025	3.45	107.98	1.44	0.06	112.94

Source: Andhra Pradesh Water Vision 2003 (GoAP 2003 a).

According to the Public Health and Municipal Engineering Department of the Government of Andhra Pradesh, the cost of water supply from groundwater sources (bore wells and subsurface water) is Rs 5 per kiloliter while that from surface water sources is Rs 10 per kiloliter; at the same time, the cost recovery is only Rs 2.25 per kiloliter. At present, diversion of surface water for drinking water schemes is 5 mld, 14 mld million liters per day and 10 mld from Godavari, Krishna and Pennar river basins, respectively. In the future, the quantity of water diverted will have to be increased to 414, 378 and 90 mld from Godavari, Krishna and Pennar river basins, respectively (GoAP 2003b).

Industrial Water

Industrial Water in IGNP Area

Except for some village-level wool manufacturing and leather and carpentry works, there were hardly any industries in the project area before IGNP. In 1951, there were 17 registered factories in Sri Ganganagar District, which rose to 85 in 1961. By 1980, the figure went up to 828, with 14,500 employees. The major contribution in the rapid growth of industries between 1961 and 1981 is due to IGNP, after the project commenced in this region in 1961. Now there are many agro-based industries flourishing in the project area.

Industrial Water in PV Link Canal Area

Andhra Pradesh ranks sixth in industrial production in India. Major industries cover information technology, bulk drugs and pharmaceuticals, basin chemicals, agro-processing, mineral-based industries, metal industries, engineering, textiles, leather, cement, sugar, power, fertilizers, gems, jewelry, papers, petrochemicals, etc. There are 242 industrial estates in the states, 3,055 medium- and large-scale units, 16,000 registered factories and 140,000 registered small-scale industries. A considerable concentration of industries can be found around the Hyderabad and Vishakhapatanam urban conglomeration. Employment in the industries increased from 0.4% in 1961 to 1.5% in 2000. By 2025, the industrial sector is expected to grow 13-fold at a growth rate of 11% per annum (GoAP 2003b). Industrial water requirement is likely to increase to 1.44 Bm^3 by 2025 from the present 0.28 Bm^3.

Issue of Water Quality

In the IGNP areas, water quality issues are connected with high levels of total dissolved solids (TDS) in groundwater. Fluoride contamination is known to occur in several patches in the area. The problem caused by high TDS and fluoride is exacerbating over time, and one of the chief advantages of the domestic water supply from IGNP is seen as the reduction in health syndromes arising out of poor water quality. In fact, the areas severely affected with these issues will be given priority in the supply of domestic water from the IGNP and the task of establishing relevant structures is expected to be completed by 2010.

The issues of water quality in the PV Link Canal areas are somewhat muted at this point in time. Coastal salinity ingress in the East Godavari District has been reported to be rising. Also, chemicals used in coastal aquaculture are said to be causing groundwater pollution which is on the rise in the Krishna District. The supply of drinking water to these areas is thus likely to have positive though somewhat less-prominent effects.

Review of Literature and Methods

This review mainly relates to literature pertaining to valuation of domestic and industrial water gains. Possible methods of valuation include the Techniques of Valuation (*source:*

www.ecosystemvaluation.org accessed on 5 October 2006). Historically, there are four major techniques that have been used to estimate economic value of ecosystem services. In this study we used the economic value of IBT water for domestic and industrial purposes.

Technique 1: Productivity Method or Production Function Approach

This approach is used to estimate the economic value of ecosystem services or products (in this study, IBT water), which contribute to the production of a market good (textile in the case of the textile manufacturing unit in Jodhpur). The production function approach can then be used to find out how changes in the quantity or quality of water supply through transfer of IBT water affect the quality or quantity of water in terms of price change (Consumer Surplus[2]) or cost changes (Producer Surplus[3]). This method is applicable when the particular resource in question is a perfect substitute for other substitutes for other inputs (e.g., import of fresh IBT water results in less usage of treatment chemicals of hitherto polluted groundwater). However, the method suffers from a critical problem of attribution where the particular resource may not be related clearly or solely to the production of marketed goods (that provision of IBT water may not be the sole reason why production will rise or, in other cases, may not be related to production of marketed goods as in the case of provision for drinking purposes).

Technique 2: Travel Cost Method (TCM)

The TCM is used to estimate the economic value of ecosystem services used for recreational purposes. The value of a new water body used for recreational purposes having both *use* and *nonuse* values (use value as boating and fishing and nonuse value as mere enjoyment of watching good scenery) is analyzed using TCM. The crux of this method is based on the Revealed Preference Approach where actual spending of a visitor in terms of Actual Travel Cost and Opportunity Cost of time spent in travel which are combined together and plotted against the rate of visits to derive a demand function that surrogates the *number of visits* ***purchased*** at *different prices*. The Consumer Surplus from this demand function is then used to calculate the economic value of this resource. Since we do not consider any recreational component in our study we opt not to use this technique.

Technique 3: Contingent Valuation Method (CVM)

The CVM is used to estimate the economic value of environments and ecosystem services and can be used for both use and nonuse values. This technique aims to compute individuals' *willingness to pay* ***contingent*** on certain hypothetical scenarios. Thus, the crux of this technique is based on the *stated preference* approach. This technique is particularly used where the value of an ecosystem service is mostly nonuse in nature and does not involve any market purchase. In this context, the import of fresh IBT water in a high TDS area will actually recharge

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[2] Consumer Surplus is defined as the area between the demand curve and the price that resembles the difference between what the consumer wants to pay for a unit of good and what he actually has to pay.

[3] Producers Surplus is defined as the area between the supply curve and the market price that resembles the price at which the producer wants to supply a commodity and the price he actually gets. It can also be interpreted in terms of cost of supply where a reduction in the cost of production will actually increase the producer surplus if not reflected in the changes in the prices.

groundwater and dilute the TDS content. But this *passive use* of IBT water remains outside the market, which can be captured through this method. Although flexible, the methodology of asking people questions rather than observing their behavior has made the technique very controversial and the economic value computed using this technique is generally taken with a pinch of salt!

Technique 4: Cost-Based Method Including Damage Control, Replacement and Substitute Cost

The cost-based approach of valuation is often used to estimate the economic value of ecosystem services in terms of Damage Cost Avoided, Replacement Cost and Substitute Cost. The approach is based on the theoretical assumption that if the people incur costs to avoid damages or provision for substitute services in the absence of the service in question then the services must be worth at least what is paid to avoid, replace or substitute those services. *Damage Cost Avoided Method* uses either the value of property protected or the cost of actions taken to avoid damages as a measure of economic value of that service. In the context of this study, the cost incurred in setting up a filtration plant or reverse osmosis (RO) plant in the case of industrial use or fuel cost in boiling water in the case of domestic use would be an appropriate surrogate of value of supply of fresh IBT water for domestic and industrial purposes.

The *Replacement Cost Method* uses the cost of replacing an ecosystem or its services as an estimate of the value of those services. In the context of our study, if high TDS content of groundwater causes erosion of boilers in the chilling plant of URMUL Dairy and thus compels the industry to frequently replace the boiler or if a textile unit located in Jodhpur plans to shift its entire production unit to another place because the contaminated groundwater in Jodhpur actually affects their production then the cost of this replacement or relocation can act as a surrogate value of supplying fresh IBT water to industrial units.

The *Substitute Cost Method* uses the cost of providing substitute services as an estimate of the economic value of the ecosystem service. In the case of our study, the value of supplying fresh IBT water could be the extra cost that the people (or units) incur while extracting groundwater (which may include both pumping cost and quality impacts) or opportunity cost in the case of an alternate source (in the case of purchase of tanker water or walking long distances to a canal source or another village source to collect freshwater).

Method Adopted

For Domestic Water Supply

Humans and cattle, among others, have to obtain a minimum supply of water for survival. The costs involved in obtaining the water are direct, indirect as well as in the nature of opportunity gain/loss.

- Direct costs are those costs the consumers pay.
- Indirect costs are those imposed upon the users due to aspects of reliability and water quality.

- Opportunity gains or losses arise out of saving or increase in drudgery, labor, investment (saving) of time and the consequential effects such as reduction in dropping in school attendance, effect on health, etc.

Direct costs paid out for obtaining water supply from alternative sources are the easiest to justify save for the fact that in a majority of the cases there is a significant element of subsidy given by state agencies to the actual users. Thus, the costs paid out by actual user households are not economic costs.[4] The economic costs are absorbed by the water supply agencies and the decisions on water levies to users are taken on the basis of parameters only one of which is these direct paid-out costs. Thus, wherever households use water supplied by public agencies, we need to look at costs incurred by these agencies and not by the households themselves except so far as the households have to resort to self-provisioning when the public institutions perform inadequately or unreliably. An assessment of the reliability and adequacy of the water supply by public agencies and the costs paid out by users when the water from these sources is not available is therefore necessary. The costs paid out by these agencies would be in the nature of revenue expenditure on staff salaries, maintenance and power consumption, etc., as well as amortized components of the capital costs in installing water extraction, storage, and purification and distribution systems. Some of these systems are/would be used by these agencies even if the IBT water replaces current sources. Further, the use of IBT water would perhaps entail installation of devices for conveying water from canal heads to cities, etc. The gain to the system is therefore the difference between the existing paid-out costs and the new costs.

Indirect costs arise due to effects of water quality. Wherever groundwater has high TDS or has contaminants such as fluorine, treatment costs as well as costs in terms of lost wages are imposed on users. Efforts have been exerted elsewhere to quantify these costs. There is a wide diversity in situations concerning occurrence of contaminants and dissolved salts across the region where IBT water is expected to flow in both the regions. Second, the assessment of treatment costs and lost wages is a somewhat speculative exercise. In view of this, although we propose to recognize these costs exist we choose to ignore them.

Householders who had to fetch water from far-off sources previously get opportunity gains. Since fetching water is a task most often left to women and children of the households, the task imposes severe drudgery on women and also leads to reduced attendance in schools and health effects on young children. Easier and smoother supply of water using IBT water coming into the village reduces this drudgery and investment of time and also contributes to enhanced health and school attendance. Among these costs, the most directly measurable are the "equivalent lost wage costs" for the time an adult woman has to spend on fetching water, assuming, of course, that she has wage opportunities available on all the days of the year. The gains due to health effects or increased attendance in schools, etc., are real but pose much difficulty in valuation as they involve speculative assessment. Hence, we will consider only the reduction in lost wage opportunity as the net gain due to IBT water.

Industrial Water Supply

Often, industrial activity in a location in India fails to come up only for want of a reliable water supply. It is only when the entire value-addition in the industries which progress in a location

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[4] Actual cost incurred for water supply varies from Rs 15 to 20 per 1,000 liters, while it is charged only Rs 1-5 per 1,000 liters.

after IBT water reaches it that it can be directly attributed to the water supply. However, it can be argued that industries which fail to progress in place A do so in place B within the country. As one is looking at costs and benefits at the national level and so long as one does not explicitly place a value on a specific location of industries this is not a material consideration. To argue that a certain industrial activity arises solely because water has become available from IBT is untenable unless one can demonstrate that water at a specific place has a particular contribution which another place would not have. In view of this, we do not choose to value industrial activity made possible by the arrival of water from IBT at the full value-added level.

The other advantage of water supply from IBT water comes in two forms. The first is in avoidance of costs (both, amortized capital costs and revenue costs of electricity consumed, etc.) incurred in obtaining water from alternative sources. Thus, if an industrial unit obtains water from groundwater sources and subsequently starts obtaining water from IBT sources, then the net consideration is the savings made by the industrial unit in terms of electricity consumed, etc. The second benefit arises from the fact that the treatment costs on freshwater supply from canals in the IBT schemes may possibly be lower than the treatment costs for water obtained from alternative sources. It is tenable to argue that costs in demineralizing water obtained from IBT sources would be smaller compared to those in demineralizing water from groundwater sources (Kumar et al. 2002). The third benefit that arises in certain cases is because use of better-quality water may enhance the quality of the product and hence fetch a better price. We propose to consider these three benefits.

Sources of Data

Secondary data were collected from Bikaner, Hanumangarh, Jaipur and Jaisalmer offices of the Indira Gandhi Nahar Board; all district offices, websites, annual reports, Census 2001 and District Statistical Handbooks of the Public Health Engineering Department (PHED); District Industrial Centre (DIC) and Rajasthan Industrial Investment Corporation (RIICO) offices in various districts; and from State's Economic and Statistical Department and its publications. Primary data collection was carried out with the help of Urmul Trust, Bikaner. Data for the exercise were obtained from three sources.

a. Secondary data sources were used for gathering information on the reach of the domestic water supply schemes based on the two canals. These included the departments connected with drinking water supply in Rajasthan and Andhra Pradesh.
b. Primary data at the level of households and villages were obtained by conducting a primary survey as outlined below.

The survey was conducted in 10 districts of Rajasthan. In eight districts IGNP water is being supplied for drinking and industrial purposes. These are Hanumangarh, Sri Ganganagar, Bikaner, Churu, Jhunjhanu, Jaisalmer, Jodhpur and Barmer. Sikar and Najaur will receive IGNP water very shortly. By and large, the study covered 497 households from 50 villages of 10 districts. The data represent the population of more than 225,000.

Identification of Samples for Drinking Water

The sample villages were identified based on three criteria: villages depending upon canal water, villages depending solely on groundwater and villages with a combination of these two. Cities were identified based on the urban classifications, i.e., Class-I to Class-VI. Representative towns/cities from all the urban classes were identified for the sample survey. Altogether, 17 towns/cities were identified. Lists of the sample villages and towns/cities are given in Tables 10 and 15. Households in these villages were identified randomly. In most of the villages, one household from each *vaas* (hamlet) was identified and the householders interviewed with the help of a questionnaire. The household survey form comprised information related to family members, age, income, primary and alternative sources of drinking water during normal and scarcity periods, direct cost paid out to obtain the water, time spent to collect from sources, etc.

Apart from the household survey, village-level information was collected using the village-level survey form, which mainly covered data pertaining to water supply, its source, head works, methods of water supply, number of connections, tariff structure and recovery, type of treatment given, etc. Similarly, town- and city-level survey forms were filled out. These forms were filled out by the survey team as per the information given by the administrative personnel. The survey was conducted by a team of five persons from December 2006 to February 2007. This team had conducted surveys in all the 10 districts in around 10 weeks' time. To reduce sample biases, the same survey team had covered all the sample villages and households.

A similar procedure was followed in Andhra Pradesh. The survey work was done in Vishakhapattanam, East Godavari, West Godavari and Krishna districts. In these districts, 359 households in 36 villages were covered. The survey instruments for the two regions of IGNP canal command area and PV Link were the same. These were translated into the local language and administered with the help of the partners: URMUL Trust in the case of IGNP and a consultant, Nikhil Mathur, in the case of AP. Prior to a full-fledged survey, the instruments were tested in Anand and the two respective areas.

Data from urban centers were obtained through personal interviews with the appropriate municipal authorities as well as selected key informants as outlined below. In urban centers, information from the secondary sources was collected to determine the cost paid out by the households. Survey of tanker water suppliers, interviews of water supply department engineers, and several indirect methods were used to estimate the economic costs of urban water scarcity. These include using alternative costs of shortages paid out by the households and the average number of days of water scarcity.

Sample Characterization

Sample Characteristics of Rural Drinking Water, IGNP

In the IGNP areas, 497 households were surveyed. In the sample, the average age of the respondents was 47 years, while the average family size was 7.3 persons per household, with the lowest, 5.9, in Barmer and the highest, 9.5, in Bikaner. A family's average monthly income was found to be Rs 3,643. The highest monthly income (Rs 5,909) was found in the Sikar District and the lowest (Rs 2,481) in Churu. Mean monthly income was found to be Rs 3,646 (Table 5).

Table 5. Average family size and income of the respondents.

District	Average age of respondents	Average family size	Average income (Rs)
Barmer	44	5.9	3,080
Bikaner	45	9.5	2,624
Churu	46	7.7	2,481
Jaisalmer	52	8.0	4,175
Hanumangarh	51	6.9	3,240
Ganganagar	50	6.1	2,860
Najaur	44	7.2	2,945
Sikar	51	7.7	5,909
Jodhpur	45	7.0	3,613
Jhunjhanu	46	6.8	5,506
Mean	47	7.3	3,643

The occupations of the heads of the households are given in Table 6. As can be determined, 35% of the households were agriculturists, 43% engaged in other diverse occupations and the rest primarily wage earners, mostly in agriculture.

Households discussed problems of fetching domestic water in "normal" months and "months of scarcity." The durations of the normal and scarcity periods across the sampled villages are given in Annex 1, and for districts are in Table 7.

Table 6. Primary occupation of the heads of the sample families.

Primary occupation	Labor	Agriculture	Others	Total
Barmer	22	10	18	50
Bikaner	9	23	18	50
Churu		32	18	50
Jaisalmer	8	18	24	50
Hanumangarh	14	9	25	48
Ganganagar	10	17	23	50
Najaur	16	17	17	50
Sikar	9	21	19	49
Jodhpur	9	9	32	50
Jhunjhanu	9	20	21	50
Total	106	176	215	497

Table 7. Duration of normal and scarcity months.

District	Duration of "normal" period (months)	Duration of "scarcity" period (months)
Barmer	7.34	4.66
Bikaner	9.64	2.36
Churu	11.38	0.62
Hanumangarh	10.98	1.02
Jhunjhanu	11.62	0.38
Jaisalmer	11.46	0.54
Jodhpur	10.70	1.30
Najaur	10.56	1.43
Sikar	11.90	0.10
Ganganagar	10.16	1.84

The average water consumption (liters per capita per day, lpcd) by households as well as the storage capacity (in number of days of supply) created by the households at the home level are given in Table 8. The average water consumption in the study area is 47.1 lpcd and mean storage capacity is about a week. It may be noted that a few households had in-house sanitation facilities and, hence, that this suppresses the daily water consumption.

Table 8. District-wise water consumption and household storage capacity.

District	Average water use (lpcd)	Average storage capacity (no. of days)
Barmer	52.18	9.79
Bikaner	48.67	7.28
Churu	46.89	3.12
Hanumangarh	48.20	1.90
Jaisalmer	54.94	8.68
Jhunjhanu	38.80	4.31
Jodhpur	54.30	16.70
Najaur	38.33	15.07
Sikar	45.20	1.00
Sri Ganganagar	43.50	4.35
Mean	47.10	7.20

The data on consumption and storage were related to reported household incomes. The difference in consumption levels as well as storage capacity across income levels is insignificant (Table 9).

Table 9. Group-wise income, water consumption and household storage capacity

Income group (Rs)	Average water use (lpcd)	Average storage capacity (no. of days)
Up to 2000	46.96	7.37
2,000-6,000	48.34	7.16
Above 6,000	48.61	5.31
Mean	47.97	6.61

Note: Average water use and storage capacity in number of days may not be the same in Tables 8 and 9, as around 10% of samples did not give information about the monthly income.

Table 10 shows the main source of domestic water for the households. There are three groups of villages: those adjacent to the canal as they get their water from the canal without the creation of any new systems; those which are primarily dependent on the groundwater and will eventually be brought under the schemes and the third group where both sources are currently in use. The data show that 307 households depended on groundwater for their domestic water requirements (Table 10).

Table 10. Sample villages and main sources of water.

Village	Block	District	Source of water supply	No. of samples
Ashotra	Balatra	Barmer	GW	10
Badi khuri	Sikar	Sikar	GW	10
Bhakra	Jhunjhanu	Jhunjhanu	GW	10
Banad	Jodhpur	Jodhpur	GW	10
Bandhrau	Sardarsahar	Churu	SW	10
Basanpeer	Jaisalmar	Jaisalmar	GW	10
Bhadana	Najaur	Najaur	GW	10
Bhadhadar	Sikar	Sikar	GW	10
Bhairupura	Sikar	Sikar	GW	10
Bhamatsar	Nokha	Bikaner	GW	10
Budana	Jhunjhanu	Jhunjhanu	GW	10
Chandan	Jaisalmar	Jaisalmar	GW	10
Chudela	Malsisar	Jhunjhanu	GW	10
Daizar	Jodhpur	Jodhpur	GW and SW	10
Dangiyabas	Jodhpur	Jodhpur	GW and SW	10
Dantiwara	Jodhpur	Jodhpur	SW	10
Desusar	Jhunjhanu	Jhunjhanu	GW	10
Devliya	Jodhpur	Jodhpur	SW	10
Dhassu Ka Bass	Laxmangarh	Sikar	GW	10
Dholipal	Hanumangarh	Hanumangarh	SW	10
Didiya Kala	Jayal	Najaur	GW	10

Ganeshgarh	Ganganagar	Ganganagar	SW	10
Hameera	Jaisalmar	Jaisalmar	GW	9
Jasol	Panchpadra	Barmer	GW	10
Junjala	Jayal	Najaur	GW	10
Kikasar	Sardarsahar	Churu	SW	10
Kuship	Siwana	Barmer	GW	10
Mahiyawali	Ganganagar	Ganganagar	SW	10
Malkasar	Sardarsahar	Churu	SW	10
Malsar	Sardarsahar	Churu	SW	10
Manaksar	Hanumangarh	Hanumangarh	SW	10
Manjhu Bass	Padampur	Ganganagar	SW	10
Mevanagar	Panchpadra	Barmer	GW	10
Naradhana	Jayal	Najaur	GW	9
Nayana	Hanumangarh	Hanumangarh	GW and SW	10
Nokha	Nokha	Bikaner	GW	10
Padardi	Siwana	Barmer	GW	10
Parwa	Nokha	Bikaner	GW	10
Patamdesar	Sardarsahar	Churu	SW	10
Rashid pura	Sikar	Sikar	GW	10
Rasisar	Nokha	Bikaner	GW	10
Ratewala	Padampur	Ganganagar	SW	10
Rijani	Alsisar	Jhunjhanu	GW	10
Rodawali	Hanumangarh	Hanumangarh	GW and SW	10
Roll	Jayal	Najaur	GW	10
Sanwatsar	Padampur	S.ganganagar	SW	10
Satipura	Hanumangarh	Hanumangarh	GW and SW	10
Sodakor	Jaisalmar	Jaisalmar	GW	9
Somalsar	Nokha	Bikaner	GW	10
Thaieyat	Jaisalmar	Jaisalmar	GW	10
Total samples				497

Note: GW = groundwater; SW = surface water.

Source: Primary data.

Table 11 shows the distance of the main sources of water from the household.

Table 11. Average distance (km) of source of water.

District	Normal time primary source	Scarcity time primary source	Normal time alternative source	Scarcity time alternative source
Barmer	0.27	3.27	0.00	3.35
Bikaner	0.43	0.89	0.00	0.95
Churu	0.05	0.49	0.00	0.84
Hanumangarh	0.07	0.49	0.01	0.60
Jaisalmer	0.37	0.37	0.01	0.36
Jhunjhanu	0.20	0.03	0.00	0.05
Jodhpur	0.81	3.25	0.00	4.47
Najaur	0.62	1.57	0.05	1.62
Sikar	0.05	0.02	0.00	0.01
Sri Ganganagar	0.36	0.53	0.00	0.68
Mean	0.3	1.1	0.0	1.3

Source: Primary data.

The average travel distance to fetch water as per the main source of village is given in Table 12. This is given for the normal period and the scarcity time. Not many people rely on alternative sources during normal time and similarly not many people rely on primary sources during scarcity time. Very interestingly, it was found that villagers depending only on groundwater sources were traveling longer distances than those depending on canal water sources.

Table 12. Average travel distance in villages for fetching water based on main source of water.

	During normal periods (km)			During scarcity time (km)		
District	Ground-water	Surface water	Both groundwater and surface water	Ground-water	Surface water	Both groundwater and surface water
Barmer	0.27			3.43		
Bikaner	0.43			0.95		
Churu		0.05			0.84	
Hanumangarh		0.05	0.08		0.74	0.37
Jaisalmer	0.37			0.36		
Jhunjhanu	0.20			0.05		
Jodhpur	0.61	0.45	1.28	8.20	5.65	2.49
Najaur	0.62			1.66		
Sikar	0.05			0.03		
Sri Ganganagar		0.36			0.68	
Mean	0.36	0.23	0.68	2.10	1.98	1.43

The fees were paid not only to owners of water sources including the Panchayats, but also to tanker suppliers and other individuals or institutions. The data show that households paid, on average, Rs 6.50 per month for fetching their water during normal periods and around Rs 24 per month during scarcity periods (Table 13). Many people did not pay any fee for water including Panchayats (188 of 497 respondents). Similarly, it can be seen from the Table that the cost paid by the people residing in canal water supplied villages was lesser than that paid by villagers depending on groundwater.

Table 13. Average paid out cost per month per household (Rs).

District	All samples		Canal water villages		Groundwater villages	
	Normal period	Scarcity period	Normal period	Scarcity period	Normal period	Scarcity period
Barmer	10.80	404.00			10.80	404.00
Bikaner	61.70	242.80			61.70	242.80
Churu	47.94	48.00	47.94	48.00		
Hanumangarh	22.72	53.00	19.05	52.50		
Jhunjhanu	45.48	40.83			45.48	40.83
Jaisalmer	69.45	46.00			69.45	46.00
Jodhpur	44.02	346.00	30.05	340.00	0.00	480.00
Najaur	67.41	213.88			67.41	213.88
Sikar	36.15	1.20			36.15	1.20
Sri Ganganagar	22.14	59.60	22.14	59.60		
Mean	42.78	145.53	29.80	125.03	41.57	204.10

It was found in the samples that the average paid-out cost for water was 4% of the income though it varied from 0% to 40%

The time spent by the households in fetching their water each day as well as the breakup of this time across the category of individuals engaged in the task are given in Table 14. It was found that average time taken to fetch water was higher during a normal period than in a scarcity period.

Table 14. Average of daily hours spent in collecting water.

District	Normal period				Scarcity period			
	Others	Child	Female	Male	Others	Child	Female	Male
Barmer		3.00	1.24	3.00	2.38	0.00	1.03	0.00
Bikaner			1.18	1.94			0.83	0.22
Churu			1.20				0.43	
Hanumangarh			0.68	0.50			1.12	0.00
Jaisalmer	0.95		1.71	1.21	0.20		0.15	0.14
Jhunjhanu	0.90		0.78		0.00		0.30	
Jodhpur	1.17	2.00	1.98	3.00	0.83	2.00	0.53	0.00
Najaur			1.88	0.83			0.53	0.67
Sikar			0.91				0.04	
Sri Ganganagar	0.00		0.67		1.00		0.68	
Mean	0.60	2.50	1.22	1.75	0.88	1.00	0.56	0.17

Urban Drinking Water

Of the 16 urban centers studied, four obtained their domestic water purely from surface water sources, another four from both surface water and groundwater sources while the remaining eight depended entirely on groundwater. The mean water supply given to these centers by the municipal authorities ranged between 70 and 191 lpcd (Table 15).

Table 15. Urban water supply standards, actual supply and electricity consumption for groundwater pumping.

Town	Source	Water supply norm	Supply (lpcd)	Electricity consumption, (kWh/day)[5]
Pokaran	Groundwater	70	117	na
Najaur	Groundwater	100	70	248
Nokha	Groundwater	100	111	373
Churu	Surface water and groundwater	70		na
Hanumangarh	Surface water	90		
Ravatsar	Surface water	100	109	
Jaisalmer	Surface water and groundwater	70	87	na
Barmer	Surface water and groundwater	135	85	na
Jhunjhanu		100	88	
Bagar	Groundwater	100	116	9
Sadulsahar	Surface water	100	99	
Suratgarh	Surface water	135	120	
Fatehpur	Groundwater	100	89	77
Pilibanga	Groundwater	70	191	na
Bikaner	Surface water and groundwater	130	107	na

Sample Characterization of Industrial Water Use

There are no major industries in the ten districts where the survey was undertaken except for a few thermal- or lignite-based power projects (the information for the same is given in the report in the subsequent section). Altogether, 25 industries were surveyed, which covered cotton ginning mills, textiles, agro-based industries, food processing units and others. All the samples were from small-scale industries. We found that almost all the industries depended on the Rajasthan Industrial Investment Corporation (RIICO, Government of Rajasthan) for water supply for daily needs. The water supply by RIICO is often not enough; hence, undersupplied water was managed from private bore wells. Now, very few industrial estates are supplied with IGNP water by RIICO.

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[5] Authors' estimate based on data available on groundwater levels.

EI = (P X 100,000) / (Q X hs X 3600), where, EI = Energy Index (assumed 50%); P = power consumption, kWh; Q = discharge rate, liters per second (assumed 18 hours of pumping per day); hs = static head in meters.

Industrial estates in Hanumangadh and two industrial estates in Bikaner are currently supplied with IGNP canal water. Quality requirement of water varies across industries. Industrial water requirement is mainly for process and waste disposal (chemical, pulp and paper, petroleum refining and primary metal) and cooling (thermal power plants). Except for most of the small-scale industries (SSI), water is mainly required for drinking, sprinkling, gardening and other housekeeping activities. A modicum of water is needed for these purposes. Among the SSI, only textile units (bleaching and dying units) need water preferably potable. If the desirable quality and quantity of water are supplied or undersupplied to these industries, the latter manage to get the water from private tanker owners, who normally get water from groundwater from nearby sources. For example, in the Balotara industrial estate of Pachpadra block of Barmer District, textile units for bleaching are flourishing because of the rich groundwater aquifer. But the quality of water is still not good enough for dying the bleached cloths. Jodhpur enjoys a great advantage because of its good-quality (less-saline) canal water (IGNP) and its proximity to Balotara; all the dying work is carried out in the textile units of the Jodhpur industrial estates.

Polavaram-Vijaywada Link Canal Areas

Sample Characterization of Rural Drinking Water

The average age of the respondents in the Vijaywada project was 39 years while the average family size was five. The district-wise details are given in Table 16.

Table 16. The average age of respondents and family size.

District	Average age of respondent	Family size
East Godavari	40.28	5.0
Krishna	41.43	4.7
Vishakapatnam	38.49	5.1
West Godavari	35.56	5.1
Mean	38.96	5.0

Almost half the population was associated with agriculture, either in direct farming or as agricultural laborers (Table 17).

Table 17. Primary occupation of the head of the sample families in some districts.

District	Agriculture	Laborer	Others	Total
East Godavari	38	37	84	159
Krishna	9	10	11	30
Vishakapatnam	14	22	64	100
West Godavari	16	16	38	70
Total	77	85	197	359

It was seen that water supply in the region is quite reliable. A very few days in a year were felt to be water-scarce compared to the IGNP area in Rajasthan (Table 18).

Table 18. Duration of normal and scarcity periods for water supply (in months).

District	Duration of normal period	Duration of scarcity period
East Godavari	11.80	0.20
Krishna	12.00	0.00
Vishakapatnam	11.72	0.26
West Godavari	11.89	0.25

The average water consumption was found to be 72 liters per person per day. Because of an ensured water source (groundwater or surface water) the need for household storage was very low. On average, the storage for only half the daily water requirement was created at the household level (Table 19).

Table 19. The average water consumption and household storage capacity.

District	Average water use (lpcd)	Average household storage (days)	Average household daily water use (liters)
East Godavari	73	0.4	351
Krishna	69	0.5	321
Vishakapatnam	73	0.4	363
West Godavari	72	0.6	361
Mean	72	0.5	349

The average distances of sources of water for villagers are given in Table 20. The average distance traveled was 1.6 km during the normal period and 2.3 km during the scarcity period.

Table 20. Average distance of source of water (km).

District	Normal time primary source	Scarcity time primary source	Normal time alternative source	Scarcity time alternative source
East Godavari	1.29	2.14	1.41	2.50
Krishna	0.97		2.63	
Vishakapatnam	1.42	1.29	1.15	1.83
West Godavari	3.16	1.67	2.75	4.00
Mean	1.66	1.83	1.69	2.37

The total number of samples surveyed in the Polavaram-Vijaywada project are given in Table 21. Around 300 samples were taken from villages depending on groundwater and 50 samples were taken from villages depending on surface water. Ten samples were identified from a village having both surface water and groundwater as a source of domestic water use.

Table 21. Number of samples based on source of water.

District	Groundwater	Surface water	Both surface water and groundwater	Total
East Godavari	129	20	10	159
Krishna	30			30
Vishakapatnam	80	20		100
West Godavari	60	10		70
Total	299	50	10	359

Table 22 shows the average paid-out cost for water to private suppliers and also to the Panchayat. On average, Rs 7 was spent by families, with a maximum of Rs 1 in the Krishna District and around Rs 15 in the West Godavari District.

Table 22. Average paid-out cost per month per household (Rs).

District	Normal time primary source	Scarcity time primary source	Normal time alternative source	Scarcity time alternative source
East Godavari	7.93	0.00	0.48	0.00
Krishna	1.04	0.00	0.44	0.00
Vishakapatnam	2.95	0.00	3.50	0.00
West Godavari	14.63	0.00	2.69	0.00
Mean	7.27	0.00	1.74	0.00

The data show the time spent by household members for each category, i.e., male, female and child during normal and scarcity periods. On average, an hour was spent by each category to fetch water during normal periods. The time taken during the scarcity period was 2-4 hours, spent by adult female or male members of the household. Child labor for fetching water was used only in the West Godavari District (Tables 23 and 24).

Table 23. Time spent in collecting water during normal periods (in hours).

District	Male	Female	Child	Total
East Godavari	1.09	1.11		1.11
Krishna	0.50	0.67		0.66
Vishakapatnam		0.91		0.91
West Godavari	1.33	0.87	1.00	0.89
Mean	1.10	0.97	1.00	0.97

Table 24. Time spent in collecting water during scarcity times.

District	Male	Female	Child	Total
East Godavari	2.0	1.3		1.4
Krishna				
Vishakapatnam		2.2		2.2
West Godavari	2.0	23.0		16.0
Mean	2.0	3.7		3.5

Characterization of Urban Drinking Water

Table 25. Source of water, water supply standards and actual water supply.

Town	Source	Water supply norm	Supply (lpcd)	Electricity consumption, (kWh/day**)
Narsipatnam	Groundwater	na	17.0	8
Baligattam	Surface water	na	54.6	na
Vemulapudi	Groundwater	na	12.8	2
Anakapalli	Surface water	135	56.5	na
Kundram	Groundwater	na	7.1	2
Pudimadaka	Groundwater	na	30.6	7
Kondakarla	Groundwater	na	na	na
Nuzvid	Groundwater	100	70.3	270
Garlamudugu	Groundwater	na	21.2	5
Kunchimpudi	Groundwater	50	54.5	9
Tadepalli Gudem	Surface water	70	92.0	na
Sita Nagaram	Groundwater	na	57.1	5
Cinakondepudi	Groundwater	na	43.8	4
Peddapuram	Surface water and groundwater	na	44.4	102
Edurapalli	Surface water	80	40.7	na
Bandarulanka	Groundwater	na	34.3	2
Amalapuram	Surface water	100	187.6	na
Kondaduru	Groundwater	na	na	0
Bikkavolu	Groundwater	na	25.5	14

** Authors' estimate based on data available.

Industrial Water in Polavaram-Vijaywada (PV) Project

One of the most important duties of the PV project are to fulfill the needs of the industrial sector, flourishing in Vishakhapatnam, East Godavari and West Godavari districts. Vishakhapatnam is an especially important industrial and port city. There are large and water-intensive industries around Vishakhapatnam, such as the Vizag Steel Plant, NTPC, BHPV, HPCL, Hindustan Zinc, etc. In 2004, the Vishakhapatnam Industrial Water Supply Project (VIWSP)[6] was conceived to

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[6] The Vishakapatnam Industrial Water Supply Project (VIWSP) envisages capacity augmentation of the existing 153 km long Yeleru Left Bank Canal (YLBC) system in the East Godavari District of Andhra Pradesh, on a Build Own Operate Transfer (BOOT) basis. The YLBC presently delivers about 180 million liters per day (mld) of water from the Yeleru Reservoir to the Visakhapatnam Steel Plant (VSP). The demand in the immediate future 260 mld, would in the long run, increase to 600 mld.. The other beneficiaries will include the NTPC Power Plant, Parvada Industrial Development Area, the Vishakapatnam Municipal Corporation, the proposed Special Economic Zone and the proposed Gangavaram Port near Vishakapatnam and other upcoming industries in the Vishakapatnam-Kakinada belt.

fulfill the industrial sector's water requirement around Vishakhapatnam. Initially, a 388 mld water supply project from the Yeleru Reservoir through the 153 km long Yeleru Canal and another 388 mld water supply project from the Godavari River through a 56 km long MS (mild steel) pipeline were commissioned. It was envisaged that supply provision would double once the Polavaram project is completed.

Methodology of Estimating Net Gains

The basic premise, on which our methodology is based, is to find out the cost paid for the NEXT BEST option for the water. The difference of the cost between IGNP benefited villages/towns/cities and non-benefited areas (depending solely on groundwater) would be the direct benefit accrued. This will be calculated based on the following formula:

$V_1 = (P_1 - P_2) \times Q_1$
where, P_1 = price in non-benefited area
P_2 = price in benefited area
Q_1 = quantity of water used in non-benefited area.

In addition to this, there is a value in the time saved each day in fetching water because people may now use that time for work or other activities.

$V_2 = [(T_1 / Q_1) - (T_2 / Q_2)] \times W \times Q_1$
where, T1 = time spent water hauling in non-benefited area
Q_1 = quantity of water used in non-benefited area
T_2 = time spent water hauling in benefited area
Q_2 = quantity of water used in benefited area
W = wage rate for time spent on water hauling (daily or hourly as appropriate)

While the above difference gives the gross benefit, the net gain due to IBT would be obtained by removing the amortized capital costs of the hardware necessary for bringing the IBT scheme water to villages/cities and the O&M costs on these schemes. Thus, an estimate of these two would have to be deducted from the gross benefit.

Second, for the urban centers, we have data from the municipal authorities. The rate at which urban consumers are charged for water is an administrative decision of the concerned authority and need not enter our calculation. The actual cost incurred is the cost of accessing water as of now and the gain is likely to accrue from reduction in this access cost. For the eight cities dependent on groundwater alone this access cost is essentially the cost of pumping the water from underground aquifers. This is assessed by considering the volume and fixing a standard rate for power consumption per unit of water as well as a standard power rate of Rs 4 per kWh. The pumping cost would vary by the depth of the aquifer in the concerned city and the age of equipment. While refinement in these numbers is possible, we have taken representative numbers for illustrating the gain.

Industrial Water Supply

The northwestern part of Rajasthan does not have major or large-scale industries. Most of the districts except Jodhpur are industrially backward. Jodhpur has many medium- to large-scale industries. The reason for poor industrial development relates to inadequate development of transportation and communication facilities, lack of investment and, above all, acute water shortages. Recently, the State Government took a few policy initiatives to attract entrepreneurs from outside to set up industrial units in this area. It is envisaged and hoped that many industries will come up in this area in the near future. Almost all the industries surveyed in Rajasthan were small-scale. On average, these industries paid Rs 52.47 per m^3 of water, with a minimum of Rs 16 to a maximum of Rs 100 per m^3. Similarly, out-of-pocket cost paid for alternative sources of water supply by the industries varied from Rs 500 to nearly Rs 500,000 per year.

Power Projects

Lignite-based as well as thermal power plants are getting IGNP water or will get it in the near future (Table 26).

Table 26. Power projects in the IGNP area.

Project	District	Capacity (megawatt)
Projects already conceived		
Suratgarh Thermal Power Plant	Sriganganagar	1,250
Barsingsar	Bikaner	240
Ramgarh gas power plant	Jaisalmer	160
Projects under consideration		
Palana lignite	Bikaner	120
Guja lignite	Bikaner	240
Kapoordi lignite	Bikaner	500
Jalipa lignite	Bikaner	915
Kasnana-Igyar lignite	Najaur	100
Mathania solar thermal	Jodhpur	30
Projects for future		
Thermal plant	Najaur	500
Bishnok lignite	Bikaner	80
Giral lignite	Bikaner	100
Mertha road lignite	Najaur	125
Mokala lignite	Najaur	60
Grand total		4,170

Water is or will be supplied to these power plants from IGNP. Needless to say, without IGNP water, these plants would not have even been conceived. There are incremental benefits from the energy units generated. Here too the net gain is estimated on the cost side: the current cost of accessing water is compared with the cost of fetching water from the canal and the difference is attributed to the IBT scheme.

Apni Yojana of Rajasthan

Under the Apni Yojana scheme, the cost of establishing water supply infrastructure to the urban and rural people in the study areas has been estimated at Rs 4 billion. The estimated life of the scheme is 30 years. We have assumed this to be the gross capital cost in creating infrastructure for reaching the IGNP water for domestic purposes. The O&M costs currently average 15% of the capital costs. We have used these values and have also done sensitivity analyses on the economic life of the scheme as well as on the level of O&M costs.

Similar data for industrial water supply are not available. Water infrastructure along with other infrastructure are created by RIICO, and the industrial unit located in an estate charges for it in accordance with the industrial policy in the state. We have assumed that the cost of accessing water is paid out by RIICO at the same level as the above cost of the Apni Yojana.

Similarly, the cost of water supply from the canal was calculated as Rs 10 per m^3 for Andhra Pradesh (GoAP 2003 b)

Estimation of Gains: IGNP

Economic Benefits of Rural Water Supply

Current paid-out costs per household and hence per m^3 for non-benefited areas are given in Table 27.

Table 27. Net economic gain of rural drinking water in the IGNP area.

	Areas benefiting from groundwater				Areas benefiting from canal water				
			Total cost				Total cost		
District	Direct cost (Rs billion /yr)	Potential wage loss cost (Rs billion / yr)	Rs billion	Rs/ m^3	Direct cost (Rs billion /yr)	Potential wage loss (Rs billion / yr)	Total cost (Rs billion /yr)	Rs/ m^3	Cost of canal water supply Rs/ m^3
Barmer	0.58	1.26	1.85	53.31					3.68
Bikaner	0.23	0.38	0.61	31.83					
Churu					0.12	0.47	0.60	25.07	
Hanumangarh					0.11	0.12	0.23	12.34	
Jaisalmer	0.04	0.28	0.32	10.50					
Jhunjhanu	0.20	0.59	0.79	128.9					
Jodhpur		0.24	0.24						
Najaur	0.43	1.15	1.58	49.75					
Sikar	0.12	0.90	1.01	33.76					
Sri Ganganagar					0.08	0.44	0.53	24.79	
Average				51.35				20.73	3.68

Gw - Cc = Rs (51.35-20.73)/m^3 = Rs 30.62/m^3
where, Gw = Cost paid out in groundwater supplied villages.
CWs = Cost of canal water supply.[7]

Gw - (Cc + CWs) = Rs (30.62 – 3.68) = Rs 26.94/m^3.
Cc = Cost paid out in Canal water supplied villages .

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[7] Cost of canal water supply has been calculated from a piped drinking water supply project in Churu and Jhunjhunu districts of Rajasthan called *Apni Yojna*. Total cost was Rs 4 billion and catering to the population of 900,000 (approximately 700,000 rural and 200,000 urban). There are several assumptions taken; [1] life of the project would be 50 years, [2] urban population growth rate 2% and rural growth rate at 1.2% per annum [3] O&M 20% of capital cost and inflation 5%, [5] rural water supply at 70 lpcd and urban at 200 lpcd.

It is estimated that a rural population of 5 million is being supplied by IGNP water. The total rural population in these 10 districts is around 15 million. Hence, a population of around 10 million is still depending on groundwater. Two scenarios are given here. One is as per the present level of consumption of water, which, in average, is 47 lpcd and less than the standard norms. Scenario 2 has been calculated as per the standard norms of 70 lpcd (Table 28).

Table 28. Total net economic gain of rural drinking water in the IGNP area.

Scenario 1, GW-Cc, Rs billion	Scenario 1, GW - (Cc+Cws), Rs billion	Scenario 2, GW-Cc, Rs billion @ 70 lpcd	Scenario 2, GW - (Cc+Cws), Rs billion, @ 70 lpcd
5.289	4.653	7.822	6.882

Hence, economic benefits at the present water consumption level of 47 lpcd would be around Rs 4.7-5.3 billion per annum (Table 28). Similarly, water supply as per the standard would be Rs 6.9-7.8 billion per annum.

Economic Benefits of Urban Water Supply in IGNP

The urban population of Hanumangarh, Ganganagar District, and a part of the population of Bikaner City, Churu Town are being supplied IGNP water. According to an estimate based on the data available from IGNP only 1.2 million of the total urban population of around 5 million in these 10 districts are supplied with IGNP water. Another 3.8 million of urban population needs to be supplied with IGNP water (Table 29).

Table 29. Net economic gain of urban drinking water in IGNP area.

Average population depending on groundwater	3,800,000
Water supply standard (liters/capita/day)	200
Total water supply, (m^3)	760,000
Average kWh/m^3	0.05
Total water (m^3)	38,000
Unit rate Rs/kWh	4.00
Total (Rs/day)	152,000
Annual cost (Rs)	55,480,000

The average present water supply in the urban area is 112 lpcd. If the same supply level is maintained then the net economic gain would be Rs 31 million per annum. If we consider a supply standard of 200 lpcd, then the economic benefits would be Rs 55.5 million per annum. The total net economic gain in the domestic sector in the IGNP area is Rs 4.681 billion and on the conservative side it is Rs 7.875 billion.

Current Water Use in Industries Sampled

The total electricity generation by the power projects in the region is, on average, 3,200 million units annually. The average water needed to produce this quantity of electricity would be 496 million liters (Ml) (GoI 1999): wastewater generation rate for the thermal power plant is 155 X 10^3 liters/hour/megawatt. We assume no consumptive use to be on a higher side. The total electricity required to withdraw 496 Ml of groundwater (assuming the alternative source is groundwater) at 0.05 kWh per m^3 would be 24.8 million units. If we attribute these units at the rate of Rs 4.00 per unit, the total attributable cost would be Rs 99.2 million.

Net Gains from Polavaram-Vijaywada Project

Net Benefits from Rural Drinking Water Supply

The net benefits from drinking water supply may be seen in Table 30.

Table 30. Net economic gain of rural drinking water in the PV area.

District	Groundwater benefited areas				Canal water benefited areas				Cost of canal water supply, (Rs/ m^3)
	Direct cost (Rs billion /yr)	Potential wage loss cost (Rs billion/ yr)	Total cost (Rs billion /yr)	Cost in Rs/ m^3	Direct cost (Rs billion /yr)	Potential wage loss (Rs billion / yr)	Total cost (Rs billion /yr)	Annual cost (Rs/ m^3)	
East Godavari	0.09	4.18	4.28	2.03	0.25	1.32	1.57	14.83	3.68
Krishna	0.02	1.57	1.58	5.11		-			
Vishakapatnam	0.03	1.77	1.80	7.46		0.89	1.13	10.84	
West Godavari	0.17	3.24	3.41	3.67	0.32	2.86	.17	33.22	
Total			11.07	24.57			5.88	19.63	3.68

Gw–Cc= Rs 4.94 per m^3.
Gw – (Cc + CWs) = Rs 1.26/ m^3.
where, Gw = cost paid out in groundwater supplied villages
Cc = cost paid out in canal water supplied villages
CWs = cost of canal water supply (same as IGNP)

It is estimated that presently, out of a total rural population of 17 million, 9 million are still using groundwater. Two scenarios are given here (Table 31). One is as per the present level of consumption of water that, in average, is 72 lpcd. Hence, scenario 2 will not be different from it.

Table 31. Total net economic gain of rural drinking water, PV area.

Scenario 1, gw-Cc, Rs billion	Scenario 1, gw - (Cc+Cws), Rs billion
1.167	0.298

Economic Benefits of Urban Water Supply in the Polavaram Project

A few of the urban pockets in the West Godavari and East Godavari districts are being supplied by the Eluru canal network. The estimated population based on the data available would be 3.5 million, which can be catered to from the Polavaram project (Table 32).

Table 32. Net economic gain of urban drinking water in the PV area.

Average population depending on groundwater	3,500,000
Water supply standard (pcd)	200
Total water supply, m^3	700,000
Average kWh/ m^3	0.035
Total water, m^3	24,500
Unit rate Rs/kWh	4
Total Rs/day	98,000
Annual cost, Rs	35,770,000

The present level of water supply in the urban area is quite low. Its average is 50 lpcd. The net economic gain at the present level of water supply would be around Rs 9 million while at 200 lpcd of water supply the net economic gain would be Rs 35.7 million. The total net gain in the domestic sector in the Polavaram project would be Rs 0.307 billion at the lower side and Rs 1.203 billion at the higher side.

Net Economic Gain in the Industrial Sector in the Polavaram Project

As mentioned in the previous sections, industries around Vishakhapatnam and Gangavaram port are withdrawing water from the Godavari River. Eventually, after the completion of the Polavaram project the water supply capacity would be doubled. Hence, we do not attribute additional net gains due to a future Polavaram project (Table 33).

Summary of Net Economic Gains

Table 33. Summary of net economic gains.

Item		IGNP		PV	
		Population served (million)	NEG (Rs billion)	Population served (million)	NEG (Rs billion)
Rural drinking	Lower	10.0	4.6 – 5.2	9.0	0.298
	Upper		6.9 – 7.8		1.167
Urban drinking	Lower	3.8	0.031	3.5	0.009
	Upper		0.056		0.036
Industrial		na	0.099	na	0.0
Total	Lower	13.8	4.73	12.5	0.307
	Upper		7.056		1.203
	Expected gains		6.9		0.75

Note: NEG = Net economic gains.

Discussions and Conclusion

An attempt has been made here to estimate the net economic gains from water supply from IBT schemes to domestic and industrial sectors. The exercise is important for the chief reason that seldom does an exercise that aims for economic gains from schemes for creating large water structures explicitly consider the economic gains accruing from the use of water for domestic and industrial purposes per se. Investments in these schemes are sought to be justified by estimating the net contribution these schemes make in terms of increased production in the agriculture sector and, in the case of multipurpose schemes, in terms of value of electricity produced. Benefits such as domestic and industrial supply are mentioned but their values are not computed. We have adopted what we consider the most defensible method. The schemes are expected to supply water to domestic and industrial users. These users currently draw their supplies from some existing sources, such as groundwater. In doing so, they have to incur expenditure on energy for pumping water; and also spend hours trudging to the source of water. We have basically captured the benefits in terms of reduced energy costs and time spent on fetching water. These two benefits accrue to the economy via the agents who are directly benefited. We have valued energy at the market rate and the time saved at the going wage rate. There is a likelihood of a dispute about valuing time as it involves the tacit assumptions that there is abundant demand for labor and that time saved from daily chores of collecting water would be automatically sold in the market. Both these can be questioned on the grounds of their relevance to reality.

Yet we submit that what we have obtained is a conservative estimate of the value to these people. We have not really valued the negative utilities of drudgery, much of it regarding women. Nor have we attributed any specific gains to the salutary impacts, thus saving of children's time on improved school attendance and on health. There is little dispute that these benefits, in fact, do accrue, but there are issues about quantifying, valuing and estimating the quantum of these benefits. We have perhaps erred on the conservative side in an obvious manner in ignoring the salutary impacts on reduced health expenditure in the face of fairly known consequences of negative health impacts of groundwater with high TDS as well as contaminants such as fluorine. We have chosen to do so since the data on the extent of prevalence of health syndromes arising out of contaminated groundwater and pertaining to the cost of treatment as well as in terms of lost wages were not collected in these areas. Since we have not measured the impacts in terms of reduced drudgery, improved educational performance and avoided health impacts, we believe the above estimates to be conservative.

Demographic as well as ecological factors determine the size of these benefits. In the case of IGNP, the benefited areas are dry, with a small population. In fact, the absence of the canal may well have caused a situation that would require depopulating the region. Clearly, the scheme has high benefits in this situation. On the other hand, the benefited areas of the PV scheme, barring highland areas of Vizag, are in the delataic regions with abundant groundwater. Here the benefits are more muted. The chief advantage of the supply of PV scheme water to the Vizag industrial estate is said to be making industrial growth possible in that region. However, we have not attributed any gains from such industrial growth to the scheme since it is possible to argue that the same projects could easily come up in other regions where water is currently available without any net gains to the economy. This argument does not hold for domestic water supply in the case of IGNP as the people already exist out there and face a crunch.

An interesting question is how the benefits compare with the cost of creating the structures. The current estimate of creating the whole PV scheme, including the dam on the Godavari River at Pollavaram as well as the rehabilitation and resettlement is about Rs 13,000 crore, or Rs 130 billion. Against this, net economic gains from the industrial and domestic water supply from the canals are estimated by us here at about Rs 0.75 billion per year. This is about half a percent rate of return on an annual basis. It is, of course, a moot point whether one should consider the entire investment for this comparison, or the investment on just the canals, etc. The total package of benefits from the PV Link scheme includes enhanced industrial production, incremental irrigation and revival of irrigation in the Krishna Delta currently facing a water crisis. When viewed in their totality, the gains are not insignificant even for the PV case. The size of these benefits is much more significant in the case of the IGNP project. Here, the IGNP itself is expected to cost around Rs 20 billion and on that the gains from domestic and industrial water supply as estimated by us come to about Rs 6.9 billion. This is quite a sizeable gain and it would appear in retrospect that the scheme should be seen as making sense even if it were not to provide any irrigation benefits! The dominance of gains from domestic and industrial water supply would be a common feature in all regions which face massive distress on account of paucity of drinking water as in the case of Gujarat, Marathwada, Karnataka, etc. An argument can broached that the chief advantage of the IBT schemes proposed under the NRLP lies in reducing the distress for domestic water faced by millions of people living in western and southern India. The question whether this benefit necessarily involves the proposed configuration of irrigation hardware needs to be thought over. In conclusion, we believe that the contribution of this paper lies in its attempt at demonstrating a way of attributing, valuing and estimating benefits which have hitherto been simply written as being incidental advantages of water structures.

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Annex 1. Details of time and cost of fetching water and potential wage loss in the sampled villages.

Groundwater in IGNP

District	Name of habitat	Out-of-pocket cost to house-hold for normal, Rs/ month	Out-of-pocket cost to house-hold for scarcity, Rs/ month	Total out-of-pocket cost of house-hold Rs/ month	lpcd	Normal month	Scarcity month	Time spent-normal period-primary source	Time spent-normal period-alter-native source	Time spent during normal period, hours/ yr	Time spent-scarcity period-primary source	Time spent-scarcity period-alter-native source	Time spent during scarcity period, hours/ yr	Prevai-ling wage rate, Rs	Potential wage loss during normal time @ 8 hours/ day	Potential wage loss during scarcity time @ 8 hours/ day
Barmer	Asotara	16.40	480	151.62	50.4	8.5	3.5	1.6	0.0	408.0	1.0	1.0	210.0	82.00	4,182	2,153
	Jasol	19.40	220	36.12	66.9	11.0	1.0	1.2	0.0	379.5	0.8	0.8	48.0	92.00	4,364	552
	Kuship	18.20	43	320.19	43.6	3.2	8.8	0.9	0.0	86.4	1.5	1.6	818.4	34.00	367	3,478
	Mevanagar	0.00	590	191.75	60.7	8.1	3.9	1.0	0.0	243.0	0.5	0.6	122.9	82.00	2,491	1,259
	Padardi	0.00	300	152.50	39.3	5.9	6.1	1.4	0.0	247.8	1.6	1.6	567.3	33.00	1,022	2,340
		11	404	170	52	7	5	1.2	0.0					65	2,485	1,956
Bikaner	Bhamatsar	23.40	0.	23.40	52.8	12.0	0.0	0.9	0.0	324.0	0.0	0.0	0.0	57.00	2,309	0
	Nokha	91.00	110	95.28	43.0	9.3	2.7	1.7	0.0	460.4	0.4	0.6	81.0	45.00	2,589	456
	Parwa	50.00	164	73.75	50.2	9.5	2.5	1.8	0.0	513.0	0.7	0.8	112.5	35.00	2,244	492
	Rasisar	43.50	180	61.70	50.4	10.4	1.6	0.9	0.0	280.8	0.4	0.6	48.0	65.00	2,282	390
	Somalsar	100.60	760	375.35	46.9	7.0	5.0	1.4	0.0	283.5	1.6	1.6	480.0	16.00	567	960
		62	243	126	49	10	2	1.3	0.0					44	1,998	460
Churu	Bandhrau													29.00	0	0
	Kikasar													77.00	0	0
	Malkasarq													16.00	0	0
	Malsar													50.00	0	0
	Patamdesar													36.00	0	0
														42	0	0
Hanumangarh	Dholipal													27.00	0	0
	Manaksar													64.00	0	0
	Nayana														0	0

	Rodawali														0	0
	Satipura														0	0
														46	0	0
Jaisalmer	Basanpeer	40.00	90	44.17	67.3	11.0	1.0	1.7	0.0	544.5	0.3	0.3	15.0	27.00	1,838	51
	Chandan	86.30	46	84.96	60.3	11.6	0.4	0.9	0.0	295.8	0.1	0.1	2.4	117.00	4,326	35
	Hameera	35.56	66.67	37.28	63.3	11.3	0.7	1.6	0.0	528.9	0.1	0.1	4.4	70.00	4,628	39
	Sodakor	33.33	0	31.48	41.1	11.3	0.7	1.6	0.0	528.9	0.2	0.3	11.1	32.22	2,130	45
	Thaieyat	30.00	0	30.00	39.2	12.0	0.0	1.8	0.0	648.0	0.0	0.0	0.0	81.00	6,561	0
		45	41	46	54									65	3,897	34
Jhunjhanu	Bakra	38.20	0	36.93	42.9	11.6	0.4	0.7	0.0	243.6	0.2	0.0	1.8	111.00	3,380	25
	Budana	26.00	0	25.35	38.0	11.7	0.3	0.8	0.0	263.3	0.0	0.2	1.8	78.00	2,567	18
	Chudela	156.67	130	154.44	40.6	11.0	1.0	0.8	0.0	264.0	0.2	0.6	24.0	57.00	1,881	171
	Desusar	23.40	0	23.01	35.8	11.8	0.2	0.6	0.0	212.4	0.2	0.2	2.4	90.50	2,403	27
	Rijani	103.00	100	103.00	36.7	12.0	0.0	1.2	0.0	414.0	0.0	0.2	0.0	34.00	1,760	0
		69	46	69	39									74	2,398	48
Jodhpur	Banad	0.00	480	0.00	59.8	12.0	0.0	1.6	0.0	576.0	0.0	1.4	0.0	113.00	8,136	0
	Daizar														0	0
	Dangiyabas														0	0
	Dantiwara													21.00	0	0
	Devliya													57.00	0	0
		0	240		60									64	1,627	0
Najaur	Bhadana	208.50	360	224.91	27.7	10.7	1.3	1.4	0.0	449.4	0.9	1.0	74.1	31.00	1,741	287
	Didiya kala	27.00	238	74.48	59.2	9.3	2.7	1.9	0.0	530.1	0.7	0.7	105.3	36.00	2,385	474
	Junjala	77.00	0	75.08	26.6	11.7	0.3	1.3	0.0	438.8	0.4	0.4	7.2	33.00	1,810	30
	Naradhana	11.11	500	124.28	39.9	9.2	2.8	1.6	0.0	430.4	1.0	0.8	148.1	40.00	2,152	741
	Roll	7.80	0	7.80	36.4	12.0	0.0	2.0	0.0	720.0	0.0	0.0	0.0	75.00	6,750	0
		66	220	101	38									43	2,968	306
Sikar	Badi khuri	40.67	0	40.67	43.3	12.0	0.0	0.9	0.0	324.0	0.0	0.0	0.0	129.57	5,247	0
	Bhadhadar	24.26	0	24.06	37.9	11.9	0.1	1.1	0.0	374.9	0.0	0.1	0.3	47.00	2,202	2

	Bhairupura	40.05	6	38.92	57.4	11.6	0.4	1.1	0.0	382.8	0.1	0.1	2.4	77.00	3,684	23
	Dhassu ka bass	34.33	0	34.33	46.0	12.0	0.0	0.8	0.0	270.0	0.0	0.0	0.0	106.30	3,588	0
	Rashid pura	41.42	0	41.42	41.5	12.0	0.0	0.8	0.0	270.0	0.0	0.0	0.0	59.00	1,991	0
		36	1	36	45									84	3,343	5
Ganganagar	Ganeshgarh													46.00	0	0
	Mahiyawali													67.00	0	0
	Manjhu bass													51.50	0	0
	Ratewala													63.00	0	0
	Sanwatsar													48.80	0	0
														55	0	0

Canal Water

Barmer	Asotara												82.00	0	0
	Jasol												92.00	0	0
	Kuship												34.00	0	0
	Mevanagar												82.00	0	0
	Padardi												33.00	0	0
														0	0
Bikaner	Bhamatsar												57.00	0	0
	Nokha												45.00	0	0
	Parwa												35.00	0	0
	Rasisar												65.00	0	0
	Somalsar												16.00	0	0
														0	0
Churu	Bandhrau	45.00	52	45.70	43.2	10.8	1.2	0.8	260.2	0.4	0.7	37.8	29.00	943	137
	Kikasar	43.20	85	44.25	54.6	11.7	0.3	1.3	456.3	0.0	0.2	1.8	77.00	4,392	17
	Malkasarq	54.00	103	58.90	42.9	10.8	1.2	1.5	486.0	0.8	1.0	63.0	16.00	972	126

	Malsar	31.50	0	30.45	37.4	11.6	0.4	1.2	400.2	0.1	0.3	4.2	50.00	2,501	26
	Patamdesar	66.00	0	66.00	56.4	12.0	0.0	1.3	450.0	0.0	0.0	0.0	36.00	2,025	0
		47.94	48	49	47				0.0			0.0		2,167	61
Hanumangarh	Dholipal	21.00	65	25.03	44.1	10.9	1.1	0.7	220.7	0.2	0.5	23.1	27.00	745	78
	Manaksar	17.10	40	19.58	38.7	10.7	1.3	0.6	200.6	1.0	1.1	81.9	64.00	1,605	655
	Nayana													0	0
	Rodawali													0	0
	Satipura													0	0
		19.05	52	45	41				0.0			0.0		470	147
Jaisalmer	Basanpeer												27.00	0	0
	Chandan												117.00	0	0
	Hameera												70.00	0	0
	Sodakor												32.22	0	0
	Thaieyat												81.00	0	0
														0	0
Jhunjhanu	Bakra												111.00	0	0
	Budana												78.00	0	0
	Chudela												57.00	0	0
	Desusar												90.50	0	0
	Rijani												34.00	0	0
														0	0
Jodhpur	Banad												113.00	0	0
	Daizar													0	0
	Dangiyabas													0	0
	Dantiwara	0.10	80	3.43	47.9	11.5	0.5	1.7	586.5	0.1	0.0	1.5	21.00	1,540	4
	Devliya	60.00	600	195.00	88.8	9.0	3.0	2.3	621.0	0.8	0.8	144.0	57.00	4,425	1,026
		30.05	340		68									1,193	206
Najaur	Bhadana												31.00	0	0
	Didiya kala												36.00	0	0
	Junjala												33.00	0	0

	Naradhana												40.00	0	0
	Roll												75.00	0	0
														0	0
Sikar	Badi khuri												129.57	0	0
	Bhadhadar												47.00	0	0
	Bhairupura												77.00	0	0
	Dhassu ka bass												106.30	0	0
	Rashid pura												59.00	0	0
														0	0
Sriganganagar	Ganeshgarh	20.80	115	48.28	33.2	8.5	3.5	0.5	115.5	0.6	0.6	126.0	46.00	664	725
	Mahiyawali	20.80	0	19.93	47.7	11.5	0.5	0.6	189.8	0.2	0.5	10.5	67.00	1,589	88
	Manjhu bass	23.40	133	38.01	48.7	10.4	1.6	0.5	149.1	0.2	0.3	22.8	51.50	960	147
	Ratewala	24.90	35	27.26	40.9	9.2	2.8	1.2	317.4	1.4	1.6	243.6	63.00	2,500	1,918
	Sanwatsar	20.80	15	20.41	47.0	11.2	0.8	0.7	219.7	0.4	0.5	19.2	48.80	1,340	117
		22.14	60	31	44									1,411	599

Groundwater in PV

East Godavari	Amalapuram	7.3	0	7.30	79	11.90	0.00	0.9	2.5	1,210.8			0.0	44.25	6,697	0
	Bikkavolu	6.5	0	6.32	65	11.68	0.33	0.9	1.6	872.6	1.6	1.6	31.3	13.43	1,464	52
	Peddapuram	6.0	0	5.93	70	11.87	0.13	0.9	1.2	750.4	0.9	0.9	7.0	29.33	2,752	26
	Sita Nagaram	6.8	0	6.74	85	11.90	0.10	1.7	1.4	1,111.6	2.0	2.5	13.8	20.77	2,886	36
		7		7	75	12	0	1	2	986	1	2	13	27	3,450	29
Krishna	Nuzividu	1.5	0	1.49	69	12.00	0.00	0.7	1.3	714.6			0.0	17.33	1,548	0
		1	0	1	69	12	0	1	1	715	NA	NA	0	17	1,548	0

Vishakapatnam	Achutapuram	2.5	0	2.44	72	11.70	0.30	1.0	1.1	733.4	2.9	1.3	37.5	24.00	2,200	113
	Anakapalli	1.3	0	1.32	68	11.90	0.10	0.9	1.2	737.2	1.8	2.0	11.5	17.00	1,567	24
	Narsipatnam	3.5	0	3.35	80	11.40	0.50	0.9	1.5	816.5			0.0	20.50	2,092	0
		2		2	74	12	0	1	1	762	2	2	16	21	1,953	46
West Godavari	Pedavegi	12.5	0	12.09	75	11.93	0.40	0.9	1.7	929.1	2.0		24.0	41.00	4,762	123
	Tadepalligudem	18.0	0	18.00	71	12.00	0.00	0.9	1.6	888.0			0.0	17.67	1,961	0
		15	0	15	73	12	0	1	2	909	2	#DIV/0!	12	29	3,361	62

Canal Water in PV

East Godavari	Amalapuram	18.3	0.00	17.34	59	11.40	0.60	0.8	1.3	742.3	1.1	1.9	54.0	44.25	4,106	299
	Bikkavolu													13.43	0	0
	Peddapuram													29.33	0	0
	Sita Nagaram													20.77	0	0
		18.3	0.00	17.34	59	11.40	0.60	0.8	1.3	742.3	1.1	1.9	54.0	24.12	1,026	75
Krishna	Nuzividu													17.33	0	0
														17.33	0	0
Vishakapatnam	Achutapuram													24.00	0	0
	Anakapalli	41.0	0.00	41.00	83	12.00	0.00	0.9	1.0	703.4			0.0	17.00	1,495	0
	Narsipatnam	5.0	0.00	4.92	67	11.80	0.20	0.6	1.0	577.7	1.0	1.0	12.0	20.50	1,480	31
		23.0	0.00	22.81	75	11.90	0.10	0.8	1.0	640.1	1.0	1.0	6.0	20.50	992	10
West Godavari	Pedavegi	0.0	0.00	#DIV/0!						0.0			0.0	41.00	0	0
	Tadepalligudem	28.9	0.02	27.95	69	11.40	0.40	0.8	6.3	2,454.0	23.0	0.0	276.0	17.67	5,419	610
		28.9	0.02	27.95	69	11.40	0.40	0.8	6.3	2,454.0	23.0	0.0	276.0	29.33	2,710	305

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State of Irrigation in Tamil Nadu: Trends and Turning Points

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Introduction

Irrigation is a vital input for food security in the State of Tamil Nadu. Rice is the major staple food, accounting for three-fourths of the consumption of food grains. Irrigation covers most parts of the rice area. In 2000, 96% of the rice production was carried out under irrigation conditions. Groundwater contributes to a major part of the irrigated area. However, recent trends of groundwater water use in the state show that its abstractions in many regions exceed the total net annual recharge (CGWB 2006). Overall, groundwater exploitation exceeds 85% of the annual recharge. Moreover, irrigated areas under tank commands, once a dominant source of irrigation in Tamil Nadu, and under canal commands are decreasing. Besides, the cropping and irrigation patterns are changing to meet the increasing demand of non-grain food products. In view of the recent trends in irrigation, meeting food security in Tamil Nadu will indeed be a major challenge.

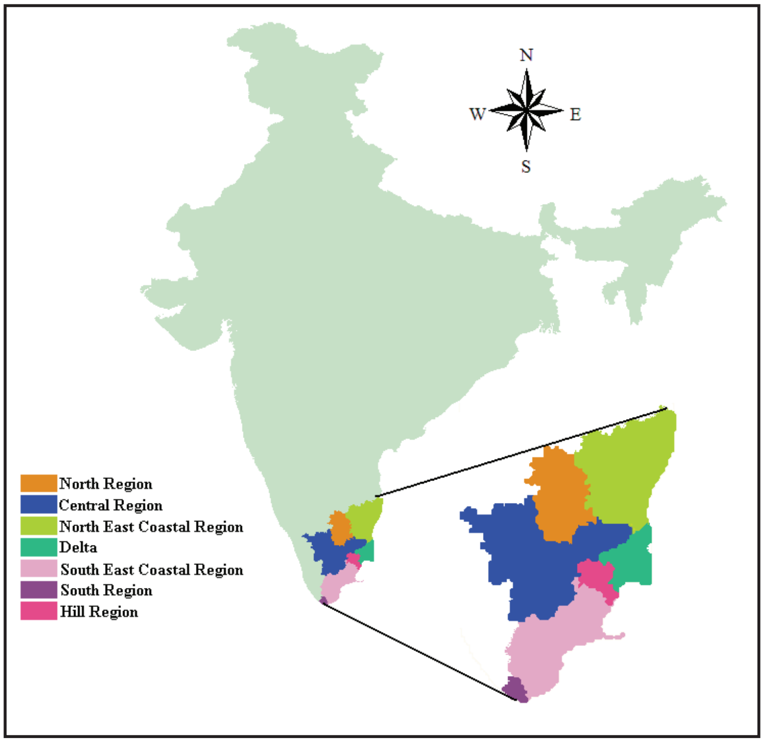
What factors have influenced these changes in the state of irrigation in Tamil Nadu, and how significant are they in the long run? Given the past trends, what types of investments in agriculture, especially in irrigation, will yield higher returns and can meet food security in the state? Answers to these questions are important for assessing future water demand, since irrigation shares more than 90% of total water withdrawals at present. The major purpose of this report is to assess the trends of irrigation development in Tamil Nadu over the last 35 years (1970-2005).

After a brief introduction to the districts and regions, in section 2 we assess the trends of major exogenous drivers that influence the water sector development. Section 3 presents the spatial and temporal trends of land use and cropping patterns, and crop production. Finally, we discuss major drivers that will influence the patterns of irrigation water use in the future.

Profile of Tamil Nadu

Tamil Nadu, located in the southeastern part of Peninsular India, with a geographical area of 13 million ha (Mha), is the tenth largest state in India (Figure 1). The state has been divided into seven agroclimatic subzones for planning agricultural development (ARPU 1991). Semiarid conditions dominate the climate in three subregions: north, northeast coastal and southeast coastal. The delta and central regions mainly have semiarid to dry-subhumid climates. These five regions consist of 97% of the total area. The average rainfall varies from 865 to 3,127 mm among subregions, and the climate of a major part of the state is categorized as semiarid to dry subhumid (Table 1).

Figure 1. Location and agroclimatic zones of Tamil Nadu.



Source: ARPU 1991.

Drivers of Change

Changing Demographic Patterns

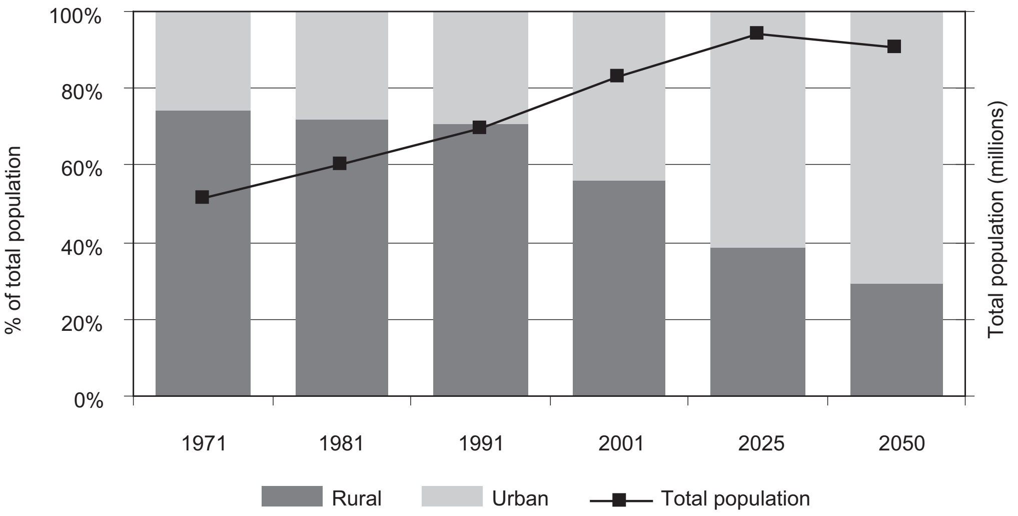
The demographic pattern in Tamil Nadu is changing rapidly, indicating major shifts in the profile of the population dependent on agriculture. In 2001, the state had a population of 62 million, accounting for 6% of India's total population and the sixth largest in all states (GOI 2001). Most (60%) of the total population still live in rural areas, but the growth of rural population became negative in the late 1990s. In 2001, the rural population was 2 million less than in 1991. Over the same period, the urban population increased by almost 12 million (Figure 2). The high growth rate of the urban population (6.1% per annum) in the 1990s indicates a substantial rural-urban migration. The data show that a majority of the population could live in urban areas before the end of this decade.

Table 1. Details of agroclimatic subregions in Tamil Nadu.

Agroclimatic subzone	District[1]	Normal rainfall (mm)	Climate	Soil types	Total population (1,000s) (rural population - % of total)			
					1971	1981	1991	2001
North	Selam	865	Semiarid	Red loamy and sandy loam	4,661 (80%)	5,439 (78%)	6,325 (78%)	7,366 (68%)
Central	Coimbatore, Madurai Trichirapalli	841	Semiarid to dry subhumid	Red and black deltaic alluvial	12,133 (69%)	14,063 (67%)	16,079 (65%)	18,451 (53%)
Northeast coastal	Chengaianna, Chennai, North Arcot South Arcot	1,036	Semiarid	Red loamy sandy coastal alluvial	10,234 (78%)	12,233 (75%)	14,601 (72%)	20,885 (51%)
Delta	Thanjavur	1,113	Semiarid to dry subhumid	Deltaic alluvial red loamy	3,833 (79%)	4,434 (78%)	4,956 (78%)	4,874 (73%)
Southeast coastal	Ramanathapuram Tirunelveli	780	Semiarid	Red and black coastal alluvial	6,052 (71%)	6,909 (68%)	7,745 (67%)	8,391 (60%)
South	Kanyakumari	3,127	Dry subhumid and perhumid	Red loamy lateritic coastal alluvial	1,228 (83%)	1,423 (83%)	1,600 (83%)	1,676 (35%)
Hills	The Nilgiris	2,226	Perhumid	Red loamy mixed red and black	491 (51%)	630 (51%)	710 (50%)	762 (40%)

[1] Districts are based on the 1991 census list.

Figure 2. Demographic trends in Tamil Nadu.



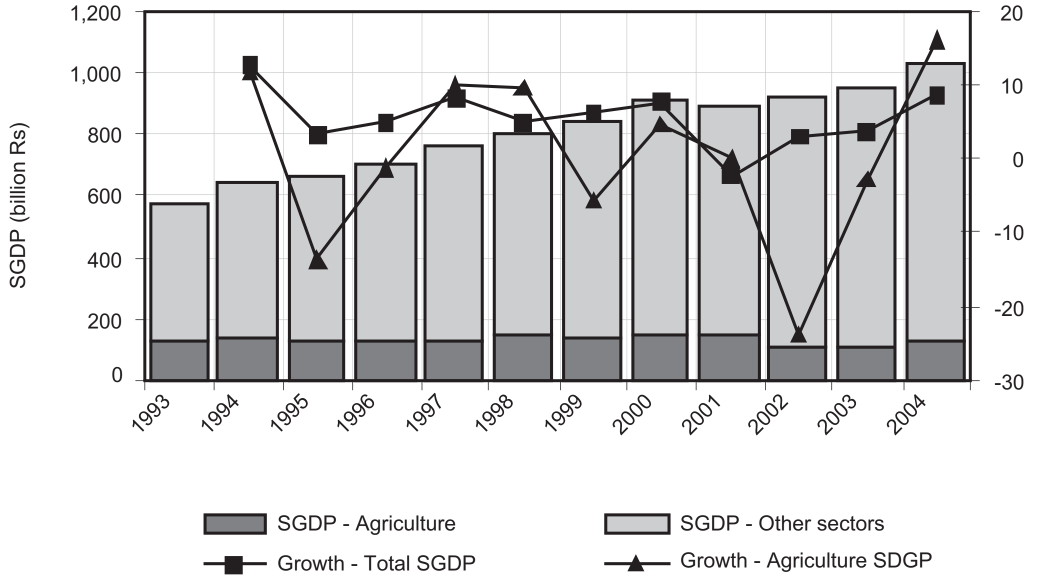
Sources: Data for 1971-2001 are from GOI 2001, and projections of 2025 and 2050 are from Mahamood and Kundu 2009.

With changing demographic patterns, dependency of rural livelihoods on agriculture is gradually decreasing. The agricultural cultivators in 2001 were 15% of the rural population, compared to 17% in 1981. However, this indicates a 0.7 million reduction in the total number of cultivators over this period. In fact, of the 21 million total workforce in 2001, only 49% were either cultivators or agricultural laborers, and the latter are only about 40% of the rural population. Such trends indicate that the contribution of the nonfarm economic activities to the overall employment has been increasing in recent years.

Economic Growth Patterns

The composition of economic growth in Tamil Nadu is fast changing. In 2005, Tamil Nadu had the seventh largest state gross domestic product (SGDP) of all the states, contributing 8% of the GDP of India. The share of agriculture in SGDP has decreased considerably over the last decade, accounting for only 12% in 2005, compared to 19.6% at the all-India level. However, annual growth of SGDP is highly variable, and the variability is largely influenced by agricultural growth (Figure 3). If growth in agricultural SGDP is very low or negative, the average growth of SDGP is 3.4%. When agricultural growth is high (>4.7%), the growth of SGDP is 8.4%, indicating that although the share of agriculture on SDGP is decreasing, high agricultural growth is a vital component for higher growth of the overall economy in the state.

Figure 3. State gross domestic product (SDGP) and annual growth.



Source: IndiaStat.com 2007.

With rapid economic growth, water demand for domestic, service and industrial sectors will increase. The total domestic and industrial water demand in India is projected to have two-threefold increases by 2050. Tamil Nadu will account for a significant part of India's additional water demand for the nonagriculture sectors. Meeting such demand in the presence of increasing water scarcities in the agriculture sector would be a serious challenge.

Changing Consumption Patterns

Food consumption patterns have been changing rapidly in recent years, affecting major changes in land use and cropping patterns. Rice is the staple food in Tamil Nadu, contributing to nutritional security of the major part of the rural population. But its consumption in both rural and urban areas has declined in recent years (Table 2). Overall, consumption of food grains per person per month has declined by 4.7% in urban areas and by 6.2% in rural areas from 1993-94 to 2004-05. This decline combined with changing demographic patterns has translated to only a 15% increase in the total demand for food grains over this period vis-à-vis a 24% growth in the total population. This reduction in demand partly explains the changing production patterns in food grains (see section 3 for a detailed discussion on cropping pattern and production changes).

Table 2. Consumption of major food items (kg/person/month) in Tamil Nadu.

Food item	Urban 1993-1994	Urban 2004-2005	Urban Annual growth (%)	Rural 1993-94	Rural 2004-05	Rural Annual growth (%)
Rice	9.25	8.58	-0.69	10.54	10.13	-0.36
Wheat	0.56	0.48	-1.29	0.22	0.20	-1.06
Other coarse cereals	0.43	0.42	-0.28	1.02	0.56	-5.33
Pulses	0.70	0.95	2.83	0.65	0.78	1.61
Total food grains	10.94	10.43	- 0.44	12.43	11.66	-0.58
Groundnut oil	0.27	0.15	-5.38	0.24	0.23	-0.39
Other edible oil	0.06	0.41	18.96	0.01	0.21	31.71
Sugar	0.65	0.69	0.52	0.46	0.49	0.50
Milk	3.95	4.82	1.83	2.11	2.48	1.48
Poultry	0.03	0.13	14.50	0.02	0.09	14.42
Eggs (numbers)	2.67	2.71	0.14	1.11	1.59	3.33

Sources: NSSO 1996, 2007.

The changes in consumption of non-grain food, which is also significant between 1993 and 2004, also influenced major changes in the cropping patterns. Over this period, consumption of milk, poultry and eggs has increased by 34%, 373% and 33%, respectively, showing a significant increase in demand. With increasing feed demand, the area under maize had a 14-fold increase between 1970 and 2005. Similarly, consumption of fruits and vegetables also increased significantly, increasing area under fruits and vegetables by 234% over the same period. With increasing income and lifestyle changes, the consumption patterns will experience further changes. As a response, cropping patterns will also undergo further changes. Next, we assess how the agriculture sector responded to these major drivers of change.

Irrigation and Crop Production: Trends and Turning Points

This section explores trends and turning points of irrigation and crop production between 1970 and 2005. The source of cropping patterns and crop production from 1971 to the late 1990s is the International Crops Research Institute for Semiarid Tropics (ICRISAT 2000), Hyderabad. The data from the late 1990s to 2005 are from two websites, namely (dacnet.nic.in/eand) of the Directorate of Economic and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India (GOI 2007), and (www.indiastat.com) of India Stat.com (IndiaStat.com 2007). This analysis only considers rainfall data of agroclimatic regions, for which the monthly estimates are available in the website of the Indian Institute of Tropical Meteorology (www.tropmet.res.in) (IITM 2007).

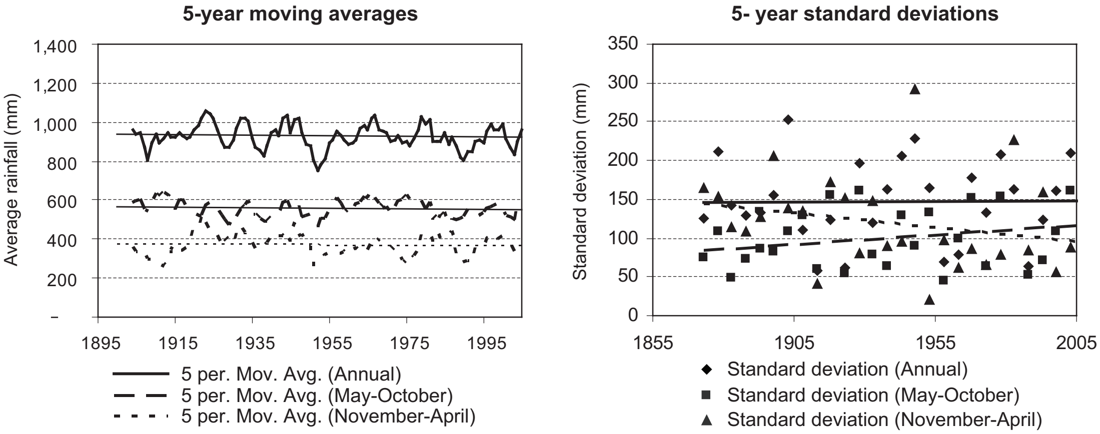
Rainfall within the state is a key determinant for both surface water and groundwater irrigation. Therefore, first we assess the long-term trends of the average seasonal and annual rainfall and their variability. Next, we explore how these rainfall trends influenced the trends of cropping and irrigation patterns in Tamil Nadu and its agroclimatic subregions. We use piece-wise linear regressions[1] for assessing the turning points and trends thereafter.

Rainfall Patterns

Bi-monsoonal patterns dominate rainfall in the sub-agroclimatic zone of Tamil Nadu. Being situated on the eastern side of the Western Ghats, most parts of Tamil Nadu miss a substantial part of dependable rainfall in the southwest monsoon. However, the southwest monsoon contributes to 60% of the annual rainfall of about 925 mm. But the southwest monsoon has high interannual variability, with a coefficient of variation close to 35%, as against 20% in the northeast monsoon. Even with the high variation of monsoonal rainfall, irrigation has played a valuable role in agricultural development in Tamil Nadu.

Long-term records show nonsignificant trends in average annual or seasonal rainfall in the agroclimatic region of Tamil Nadu (Figure 4). However, the standard deviation (over 5-year periods) of seasonal rainfall has changed over time. The variability of rainfall in the southwest monsoon (from May to October), which is most critical for crop production, has increased in recent years.

Figure 4. Annual and monthly rainfall between 1886 and 2005 in the agroclimatic subdivision of Tamil Nadu.



Source: IITM 2007.

In the past, tanks played a major role in holding the rainwater of the southwest monsoon for irrigating crops in the *rabi* (October-March) season (Gomathinayagam 2005). However, increasing variability of southwest monsoons seems to have had a significant effect on surface

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[1] The piece-wise regression model takes the form

$$y_t = \alpha_0 + \alpha_1 D_{1t} + \alpha_2 D_{2t} + \beta_0 T_t + .. + \beta_1 (T_t - T_1) D_{1t} + \beta_2 (T_t - T_2) D_{2t} + .. \\ + \gamma_0 RF_t + \gamma_1 RF_{t-1} + \gamma_2 RF_{t-2} + \gamma_3 StDev(RF)_t \varepsilon$$

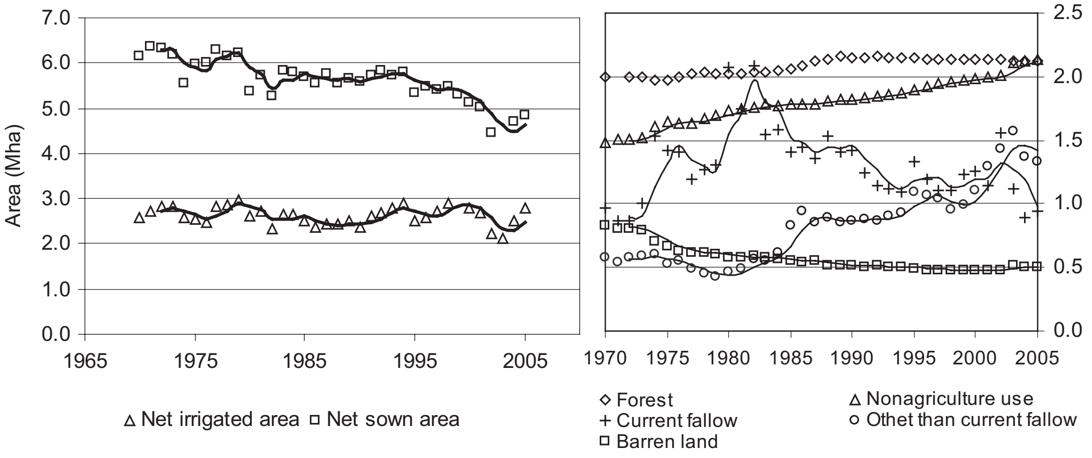
where, the indicator functions $D_{it} = I_{[t \geq T_i]}$, taking values 0 when $t < T_i$ and 1 when $t \geq T_i$, show major turning points of trends; T_t is the time trend; β_1 and β_2 show the extent of changes in trends from that before turning points; RF_t is the annual or seasonal rainfall, $RF_{t-1,}$ the lagged rainfall variables, and $StDev_t$ the standard deviation of 5-year rainfall periods.

irrigation, especially of those under tanks. As a way of mitigating the effects of increasing variability of rainfall, and also for meeting the increasing demand for irrigation, groundwater irrigation has rapidly expanded. But recent changes in many other key drivers may have had a significant effect on irrigation landscape in Tamil Nadu. We explore these in the following subsections.

Land-Use Patterns

Net sown area The net sown area (NSA) seems to have followed three distinct trend[2] patterns between 1970 and 2005 (Figure 5). The NSA has decreased at an annual rate of 0.77% during the 1970s, remained steady until the mid-1990s, and started declining again, at 2.1% annually, after 1995. Overall, the total NSA of the state has declined by 25%, or 1.5 Mha, from 6.3 Mha in 1971 to 4.8 Mha in 2005.

Figure 5. Land-use patterns in Tamil Nadu.



Among major agroclimatic subregions, the NSAs of all regions except the delta were declining (Table 1). The central region has not only the largest share, one-third of the total NSA in 2005, but also the largest contribution to the decline of about 28% between 1970 and 2005. But the biggest drop of NSA was in the northern region, where it declined by more than 40% of its peak in the early 1990s. Only the NSA in the delta region, which contributed to about 15% of the total NSA in 2005, has increased over the last three decades.

Rainfall was significant in explaining the annual variation of the average NSA. A plausible explanation for declining trends of NSA is that part of the NSA was converted to

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[2] $NSA_t = 4504 - 74^{*} T_t + 104^{*} T_{[t>1981]} - 120^{*} T_{[t>1991]} + 1.16^{*} AN\_RF_t + 0.47^{*} AN\_RF_{t-1} + 0.46^{*} AN\_RF_{t-2}$. where AN_RF is the annual rainfall, AN_RF_{t-1} and AN_RF_{t-2} are lag values of orders 1 and 2 of annual rainfall, T_t is the time trend, and * indicates statistical significance at 0.05 level. All variables in the regression are statistically significant in explaining the variation of the NSA.

nonagricultural use[3] and another significant part left as fallow for long periods of up to 1-5 years (Figure 5). The nonagricultural land (NAGL) has increased by 0.6 Mha, or 42%, between 1971 and 2005. The central and northeast regions have the highest share (27% and 26%) of NAGL and also the highest contribution (39% and 38%) to the overall increase. In fact, the NAGL of these regions has increased by 61% since 1971. Over the same period, land in the category, other than current fallow, has increased by 0.79 Mha while barren land has decreased by 0.3 Mha.

Net irrigated area. No significant trend in net irrigated area (NIA[4]) existed between 1970 and 2005 (Figure 5). Annual rainfall and lagged rainfall up to the two previous years are significant in explaining the variations of NIA. The significance of lag rainfall variables mainly shows negative effects of droughts on NIA. However, with the decline in net sown area, the share of NIA in NSA increased from 42% in 1970 to 56% in 2005.

The central and northeast coastal regions have trends of NIA similar to that of the state, and share 60% of the total NIA (Annex Table 1). That is, there are no significant trends of NIA in these two regions, except for the effects due to low rainfall patterns in consecutive years. However, NIAs of the delta and southeast coastal regions have significant declining trends, with 16% and 11% drops, respectively, from the level in the 1970s. On the other hand, NIA in the northern region, with a share of 7% of the total, has increased by 40% from 1970, and has offset the drop of NIA in other regions.

Source-wise contribution to NIA. Groundwater irrigation expanded rapidly between 1971 and 2005. Canals and tanks were the main sources of irrigation in the 1970s and 1980s, contributing to about two-thirds of the total NIA. But, groundwater has been dominating irrigation since the mid-1990s, contributing to more than half the NIA in 2005 (Figure 6).

Canal irrigation commands,[5] which have lost more than 140,000 ha between 1971 and 2005, account for only 29% of the total canal NIA (Annex Table 2). The central and deltaic regions contribute to 84% of canal NIA in 2005. Half of this loss was in the deltaic region, contributing to 52% of the total under canal commands in 2005. The central region, with the second highest canal irrigated area, also lost about 20,000 ha, but it is only 12% of the total decline in the canal NIA.

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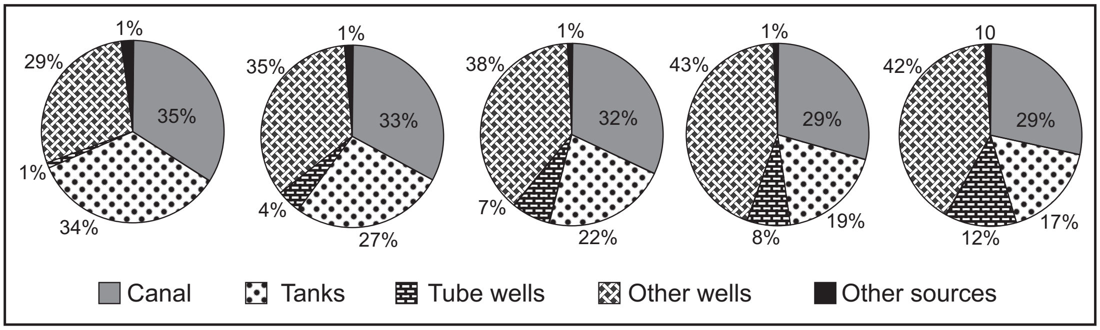
[3] Nonagricultural land included under industries, housing, roads, railways, etc.

[4] $\mathrm{NIA}_t = 5{,}299^* + 0.65^* \, AN\_RF_t + 0.56^* \, AN\_RF_{t-1} + 0.52^* \, AN\_RF_{t-}2 - 2.1 \, T_t$. Annual rainfall and its lag values are statistically significant in explaining the variation of NIA, but the time trend is not significant.

[5] $Canal\text{-}NIA_t = 22.5 + 0.00024^* An\_RF_t - 0.008^* \, T_t$. Rainfall is a significant variable for explaining the variation in net canal irrigated area, but there is a statistically significant declining trend during1971-2005.

Figure 6. Share of source-wise net irrigated area.



Tank irrigation,[6] which contributed to one-third of the total NIA in 1971, has lost more than half of its NIA by 2005 (Annex Table 2). The northeast and southeast coastal regions share three-fourths of the NIA under tanks. And these two regions lost more than 54% and 24%, respectively, of NIA under tank commands between 1971 and 2005. The central region, with 15% of total tank NIA, lost more than 27% area over the same period. Although low rainfall in three consecutive years explains the short-term variation, there seems to be a consistent declining trend in the recorded NIA under tanks during the last few decades.

However, not all of the NIA lost under tank irrigation systems, was lost from the production system. Wherever the net tank irrigated area has decreased, much of that is replaced by groundwater irrigation. This is especially true in central and northeast coastal regions, where net tank irrigated area has decreased by 103,000 and 242,000 ha, respectively, while the net groundwater irrigated area has increased by 194,000 and 307,000 ha, respectively. It seems that tanks in these areas are operating as a valuable recharge structures for utilizing groundwater irrigation.

Groundwater irrigation**,** which has contributed to a major part of NIA in recent years, had some notable trend patterns between 1971 and 2005.

- First, groundwater has replaced part of surface irrigation, especially a part of the area under tank irrigation. This pattern is prominent in the northeast coastal and central regions (Annex Table 2), where the NIA under tank commands has decreased by 243,000 and 103,000 ha, respectively, and NIA under canal irrigated areas has decreased by 38,000 and 10,000 ha, respectively. Over this period, the NIAs under groundwater in the two regions have increased by 303,000 and 195,000 ha, respectively, and have offset the loss of surface irrigated area.

- Second, groundwater irrigation has also spread well outside surface command areas. Increases in net groundwater irrigated area in central and northeast coastal regions far exceed the loss of area under surface irrigation. In the north region, increase in groundwater irrigated area is even higher than the combined area of canal and tank irrigation. Indeed, these excess groundwater irrigated areas must have occurred outside the surface command areas.

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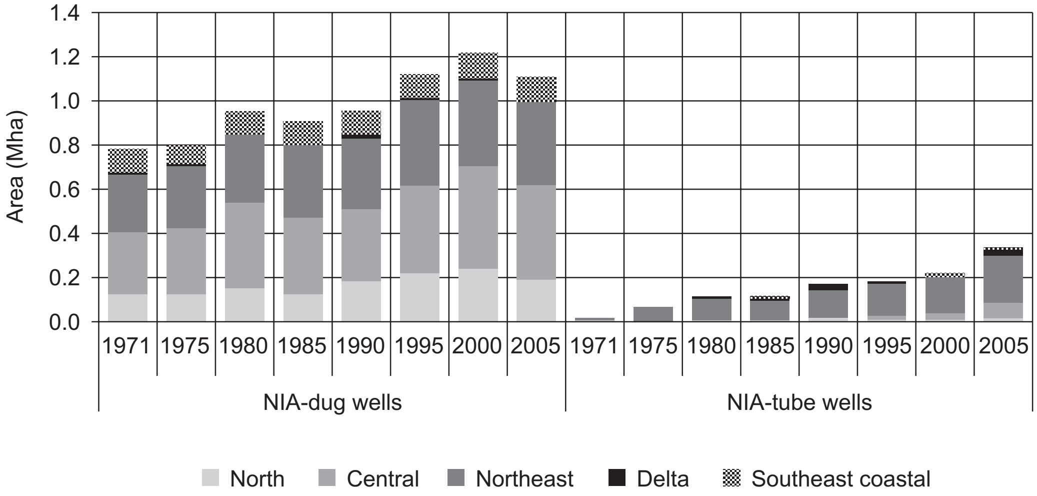
[6] $Tank\text{-}NIA_t = 48.24 + 0.05^* AN\_RF_t + 0.03^* AN\_RF_{t-1} + 0.02^* AN\_RF_{t-2} - 0.02^* T_t$. Annual rainfall and rainfall in the two previous years explain the variation in net tank irrigated area. However, in spite of these contributions, there was a significant declining trend of NIA under tank commands during 1971-2005.

- Third, recent growth patterns indicate that groundwater irrigation especially that through dug wells, is not sustainable in many regions. Dug wells were the main contributor to the growth of groundwater irrigation before late 1990s (Figure 7, right-hand graph). However, the NIA through dug wells has been decreasing in recent years. Part of this decline was due to the droughts of 2001-2003. But the declining trend seems to be continuing beyond the drought period.
- Fourth, it is clear that reliance of tube-well irrigation is increasing. In fact, tube-well irrigation seemed to be taking the place of dug wells in most regions (Figure 7, right-hand graph). The central and northeast coastal regions had the largest increase with each region recoding 34,000 ha of additional net tube-well irrigated area between 2000 and 2005. The central and northeast coastal regions had, respectively, tenfold and twofold increases in tube-well irrigated area between 1971 and 2005. Although small in magnitude, the north region also nearly doubled its tube-well irrigated area from 2000 to 2005.

Figure 7. Net dug well and net tube-well irrigated areas in agroclimatic subregions.



Impacts of groundwater development. Although groundwater development has contributed to maintaining NIA at the present level, it has led to environmental concerns in many regions. As a whole, 85% of the net groundwater resource is already developed (Annex Table 2). However, many regions are categorized as overexploited, where groundwater withdrawals far exceed the net available resources. Of the 385 blocks, 142 are overexploited. And 33 blocks are categorized as critical, where the stage of development is between 90 and 100% in both pre- and post-monsoons, and 57 are semi-critical, where the stage of development is between 70 and 100% in either pre- or post-monsoons (CGWB 2006).

Many of the blocks in the north, central and northeast coastal regions are either critical or overexploited. These regions have 74% of the net available groundwater resources of the state, but contribute to 89% of the NIA under groundwater. Indeed, sustaining groundwater irrigation at the present level is a major issue in these regions. In fact, after a continuous growth, the NIA under dug wells in all three regions has decreased between 2000 and 2005 whereas that under tube wells has increased over the same period and helped maintain a positive growth in area under groundwater irrigation.

However, with the present trends of falling groundwater tables, how long these growth patterns of groundwater irrigation can be maintained is a critical issue.

Gross irrigated area. Although the NIA remains a constant, the gross irrigated area (GIA) showed a statistically significant declining trend[7] between 1971 and 2005 (Figure 8). This indicates that the area that is irrigated more than once has declined over the last few decades. In fact, the irrigation intensity, the ratio of GIA to NIA, has declined from 131% to 112% between 1971 and 2005. As a result, the GIA has declined by 0.49 Mha, from 3.47 Mha in 1971 to 2.98 Mha by 2005.

The sharp decline[8] of irrigation intensity and hence GIA started since the mid-1990s. Part of this decline, especially the trends after 1995, can be attributed to low rainfall. But the statistically significant time trend indicates that other factors are also contributing to decrease GIA by about 3,500 ha annually. These factors include the increasing demand for water from other sectors in dominantly canal irrigated areas, and increasing variability of water supply and water scarcities and low profitability in tank irrigated areas. In fact, the largest contributions to the decline of GIA are from the delta—a region dominantly canal-irrigated, and the northeast coastal subregion—a region dominantly tank-irrigated. In both regions, GIA has decreased by 0.21 Mha (Annex Table 3). In 1971, canals contributed to 93% of the irrigation in the deltaic region, while tanks contributed to more than half the irrigation in the northeast coastal region.

Table 3. State of groundwater development.

Agroclimatic subregion	Annual replenishable groundwater resources	Net groundwater availability[1]	Annual groundwater withdrawals			Stage of groundwater development[2]
			Irrigation	Domestic and industries	Total	
	(Mm^3)	(Mm^3)	(Mm^3)	(Mm^3)	(Mm^3)	(%)
North	24.8	22.3	27.8	1.0	28.8	129.1
Central	58.5	52.6	41.6	2.3	43.9	83.4
Northeast coastal	89.4	80.4	75.7	3.0	78.7	97.9
Delta	13.8	12.4	9.5	0.8	10.3	82.8
Southeast coastal	30.4	27.4	11.1	1.1	12.2	44.7
South	2.9	2.6	0.2	0.2	0.4	16.2
Hill	10.9	9.8	1.9	.3	2.1	21.7
Tamil Nadu	230.7	207.7	167.8	8.8	176.5	85.0

Notes: [1] Net groundwater availability is the difference between annual replenishable groundwater resources and natural discharge during non-monsoonal months

[2] Stage of groundwater development is the ratio of groundwater withdrawals to net groundwater resources

Source: Authors' estimates based on CGWB 2006.

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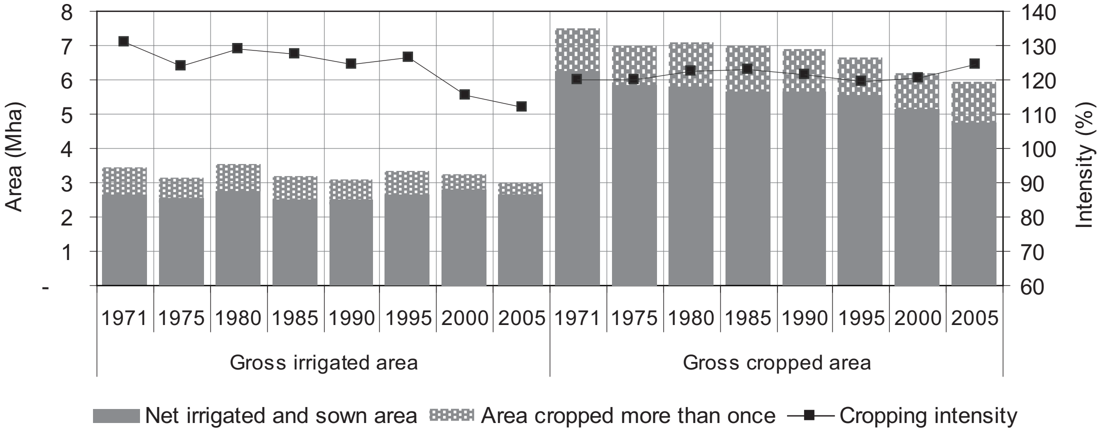
[7] $GIA_{it} = -50.1 + 1.18^{*} NIA\_CAN_{it} + 1.23^{*} NIA\_TANK_{it} + 1.65^{*} NIA\_TW_{it} + 1.16^{*} NIA\_DW_{it} + 0.08^{*} RF\_AN_{t} + 0.05^{*} RF\_AN_{t-1} - 3.5^{*} T_{t};\ R^2 = 95\%$. * indicates that the coefficients are statistically significant at the 0.05 level.

[8] $II_{t} = 95.1^{*} - 0.05\ T_{t}\ 1.5^{*}\ T_{[t>1995]} + 0.02^{*} RF\_AN_{t} + 0.01^{*}\ RF\_AN_{t-1};\ R^2 = 70\%$.

Figure 8. Gross irrigated area and irrigation intensity.



An increase in GIA was registered only in the north region. Groundwater, which contributed to two-thirds of the irrigated area in 1971, has sustained the expansion of irrigation in this region. Our analysis showed that NIAs under canals, tanks and dug wells have contributed more or less the same for expanding the GIA, where each additional ha of NIA added 1.16–1.23 ha to the GIA. However, with greater ability to pump water from deep aquifers, each hectare of net tube-well irrigated area contributed an additional 0.65 ha to the GIA.

Gross cropped area. The gross cropped area (GCA) also registered a declining trend[9] (Figure 8) similar to that of the net sown area (NSA). The GCA declined in the 1970s, remained steady during 1980s, and began declining again in the mid-1990s. Overall, GCA declined by 21%, or 1.58 Mha between 1971 and 2005 (Annex Table 3), to which the decline in NSA has contributed 94%. This shows that there are no major changes in cropping intensity (CI), ratio of GCA to NSA. The CI was 124% in 2025, compared to 120% in 1971.

The GCA has declined significantly in all regions except in the north, where it slightly increased by about 0.2 Mha. The central and southeast coastal regions have the largest share of GCA (about 54%), and are also the largest contributors to the decline in GCA (about 68%).

Cropping patterns. No major crop diversification trends from grain to non-grain crops exist in Tamil Nadu (Figure 9). Although grain-crop area has declined by about 1.41 Mha between 1971 and 2005, non-grain area has no commensurate increase over this period. In fact, the decline in food-grain area has contributed to 89% of the overall reduction in the GCA, decreasing the share of food grains in the GCA from 63% to 54% over this period.

The share of non-grain crops in the GCA increased from 37% to 45% from 1971 to 2000. However, this increase was primarily due to the reduction in area under food-grain crops. In fact, the area under non-grain crops had slightly increased before 1990, but again decreased to the level of the early 1970s. However, a change towards crop diversification occurred in the north region, where increase in area under non-grain crops exceeded the decline in area under food-grain crops by about 195,000 ha (AnnexTable 3). The expansion of groundwater

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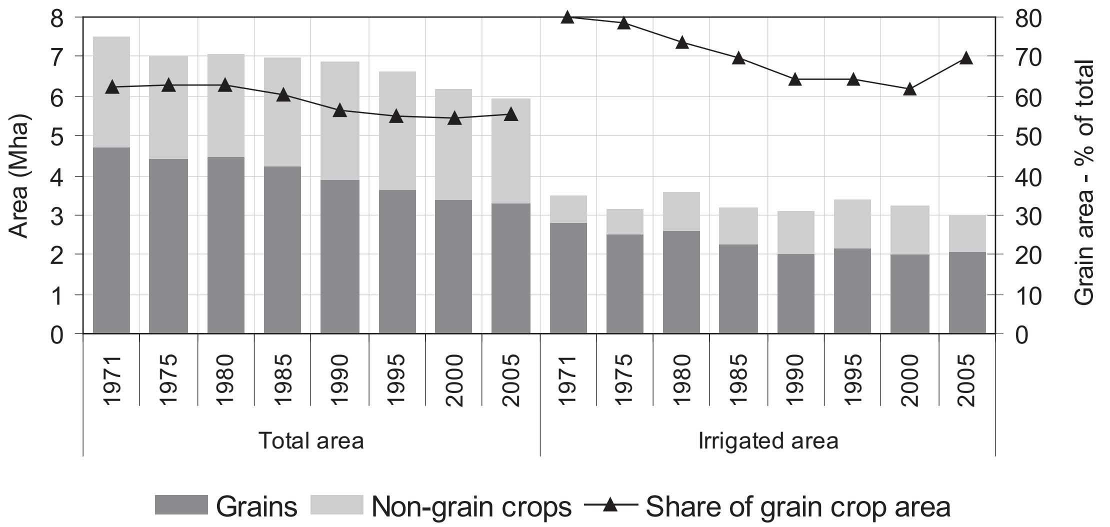
[9] $GCA_t = 4875 - 87^{*} T_t + 121^{*} T_{[t>1980]} - 148^{*} T_{[t>1995]} + 1.78^{*} AN\text{-}RF_t + 0.84^{*} AN\_Rf_{t-1} + 0.57^{*} AN\_RF_{t-2}$; $R^2 = 86\%$. * indicates statistically significant at the 0.05 level. Changes in trends from the 1970s, 1980s, and 1990s are statistically significant. Overall, there is a statistically significant declining trend of GCA.

irrigation, which dominates the land-use patterns in the north region, has contributed to this increase.

Although no major changes occurred in the overall share of GIA in the GCA, the share of irrigation in grain and non-grain crops changed sharply. Close to 80% of the GIA was under food-grain crops in 1970 and this share had decreased to 60% by 2000. This means that much of the reduction in irrigated area under food-grain crops was replaced by irrigated area of non-grain crops. In fact, between 1970 and 2000, the non-grain-crop area increased by 539,000 ha, while the grain-crop area declined by 785,000 ha. Similar trends of irrigation patterns exist in all agroclimatic regions, indicating changing preference for using scare irrigation resources, especially groundwater, for high-value non-grain crops.

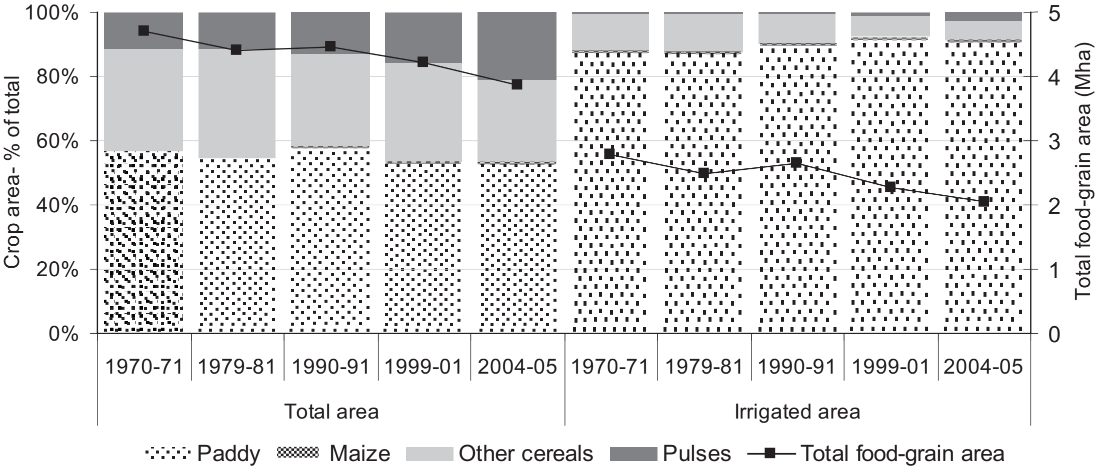
Figure 9. Cropping and irrigation patterns.



Cropping Patterns of Food Grains

Paddy dominates the cropping pattern of food grains, accounting for 60% of the total food-grain area, and more than 80% of the total food-grain irrigated area in 2005 (Figure 10). However, area under paddy has decreased over time, by 0.67 Mha of the total and by 0.64 Mha of irrigated area since 1970 (Annex Table 4). This contributed to a major part of the decline in GCA and GIA.

Figure 10. Changing cropping patterns of food-grain crops.



Although the total paddy area has decreased, the share of food grains has remained steady over time. This is primarily due to the declining area under coarse cereals. The area under coarse cereals has also declined by 64%, from 1.48 to 0.54 Mha between 1971 and 2005. Only the area under maize has increased over this period. The growth in maize area is only a recent phenomenon, and the total area under maize has more than doubled between 2000 and 2005, indicating increasing demand for livestock feed.

As in the total area, paddy dominates the irrigated area under food grains. In fact, the share of irrigated area under paddy has increased slightly, from 88% in 1970 to 94% in 2000. Irrigated area under food-grain crops, except maize and pulses, has decreased over this time. Irrigated area under maize, although small in comparison to other crops, has an eightfold increase between 1970 and 2005. This trend is expected to increase with increasing feed demand, which primarily emanates from increasing consumption of poultry products.

In fact, the changes in cropping patterns seem to be quite parallel to the changes in food consumption patterns. While the consumption of cereals is decreasing, the preference for non-grain food crops, such as vegetables and fruits, and animal products, especially for milk, poultry and eggs is increasing. The consumption of rice per person per month in urban and rural areas has slightly decreased by 0.68 and 0.41 kg, or 7% and 4%, respectively, between 1993-94 and 2004-05. And the consumption of coarse cereals has dropped drastically, especially in rural areas by about 0.46 kg or 46%. Over the same period, consumption of milk has increased by 22% and 18% in rural and urban areas, respectively, with the consumption of poultry products increasing more than threefold. The latter has increased the demand for feed, particularly for maize.

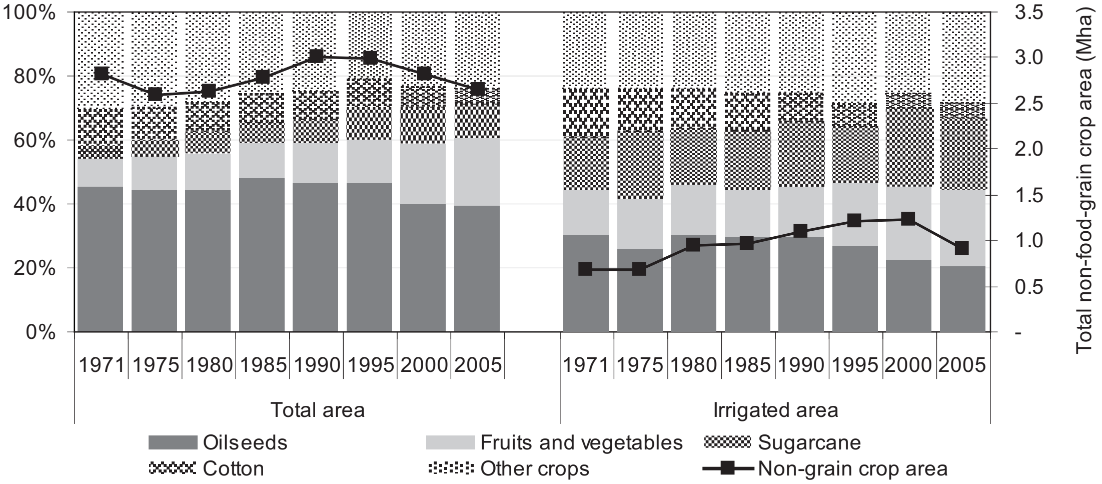
With increasing income and changing lifestyles, food consumption patterns are expected to change further (Amarasinghe et al. 2007). As a result, consumption demand, and hence the production requirement and area of coarse cereals could further decrease. The consumption demand for rice will also decrease slightly. Thus, as in the last two decades, additional demand for rice will be met primarily through increase in yield rather than through increase in area. However, area under maize will increase manifold to meet the increasing feed demand.

Cropping Patterns Non-Grain Crops

Although the total area has not increased, major changes in cropping and irrigation patterns of non-food-grain crops have occurred since the 1990s. The areas under oilseeds, once dominated non-food-grain cropping patterns, but area under cotton has decreased (Figure 11). The area under fruits, vegetables and sugarcane has more than doubled and virtually replaced the area of production of other non-food-grain crops. The area under fruits and vegetable has increased in all but the deltaic region, and area under sugarcane has increased in all regions (Annex Table 5). The area under oilseeds has declined significantly in central and northeast coastal regions, while the area under cotton has declined significantly in central and southeast coastal regions.

Although the total crop area of non-food-grain crops shows no major change, the area under irrigation increased significantly between 1971 and 2000. Only one-quarter of area under non-food-grain crops was irrigated in 1971, and this has increased by 43% by 2000. Fruits/ vegetables and sugarcane contributed to a major part of additional irrigated area in non-food-grain crops, increasing by 171,000 and 175,800 ha, respectively, between 1971 ad 2000.

Figure 11. Cropping patterns of non-food-grain crops.

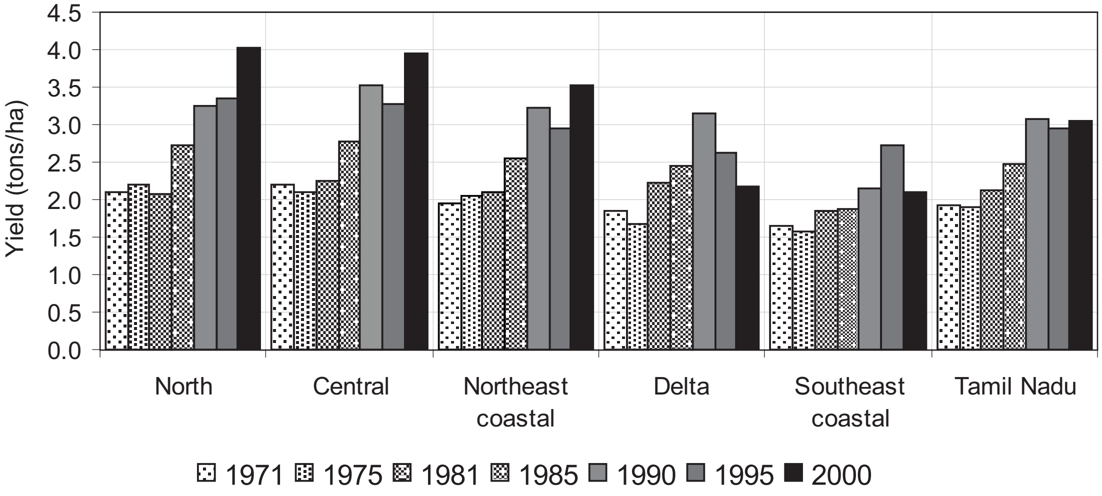


The decline in irrigated area under non-food-grain crops between 2000 and 2005, of about 320,000 ha, shown in Figure 11 may, in fact, not reflect the long-term trends. This decline is mainly due to slow recovery of irrigation in non-food-grain crops after the severe droughts between 2001 and 2003. In fact, total area under irrigated non-food-grain crops between 2000 and 2003 has declined by 458,000 ha. But with good rainfall, the declining trend was reversed and the area under irrigated non-food-grain area recovered 138,000 ha during 2004-2005. If changing consumption patterns and increasing income are indicators of future direction, the trends of increasing irrigation patterns in non-food-grain crops will most probably expand in the future. Per capita consumption of fruits and vegetables is significantly higher in urban areas than in rural ones (21% and 52%, respectively); and it increases significantly with increasing income (NSSO 2007). Thus, Tamil Nadu is rapidly changing its rural and urban structure, with increasing income. Therefore, demand for fruits and vegetables will further increase in this state.

Crop Productivity

Growth of crop productivity varies between crops and also between regions. Paddy is the major crop in Tamil Nadu, and almost the whole paddy area is irrigated. Paddy yields increased only marginally in the 1970s, and significantly (3.77% annually) in the 1980s. However, the growth in yield[10] as a whole stagnated in the 1990s (Figure 12). This is primarily due to decreased yields in the deltaic region, where canal irrigation dominates, and the stagnant yields in the southeast coastal region, where tank irrigation dominates. These two regions had 42% of the paddy area, contributing to 30% of the total paddy production in 2000. The paddy yields in the other three major paddy-producing regions, where groundwater irrigation dominates, have increased even in the 1990s.

Figure 12. Paddy yields in different agroclimatic regions (tons/ha).



Increasing reliability of irrigation supply in groundwater irrigated areas may be a factor in sustaining yield increase in the north, central and northeast coastal regions. In fact, the contribution from groundwater irrigation to the overall yield growth is about three times that of canal irrigation. The reliability of irrigation supply seemed to be lowest in canal irrigated area, where yield has been declining since 1990, as is indicated in the deltaic region. Increasing groundwater irrigation in tank command areas could have somewhat offset the negative impact due to unreliable water supply in tank irrigation, as is evident in the southeast coastal region. Changes in trends of yields of other crops are also observed in Tamil Nadu (Annex Table 6). Among these, yields of:

- sorghum, a prominent coarse cereal crop in north and northeast coastal regions, had a slight declining trend of 1.2% annually in the 1990s,
- pearl millet and finger millet, which are prominent coarse cereal crops in the north and northeast, had a slightly increasing trend of 1.6% annually in the 1990s,

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[10] $Paddy\_yld_{it}=1.87^{*}+0.0038^{*}Fertha_{it}+0.0056^{*}PctCanal_{it}+0.0154^{*}PctGW_{it}+3.67\ Roadha_{it}+-0.018^{*}StdveRF_{it}-0.007T_{t}+0.058^{*}T_{t[t>1980]}-0.082^{*}T_{t[t>1995]}$., where i=1,..5, stands for north, central, northeast coastal, deltaic and southeast coastal regions; $Fertha_{it}$ is the chemical (NPK) fertilizer use per gross cropped area; $PctCanal_{it}$ and $PctGW_{it}$ are net irrigated areas under canal and groundwater as a percent of net irrigated area; $StdevRF_{it}$ is the standard deviation of monthly rainfall. * indicates statistical significance at the 0.05 level.

- pulses are stagnating in all regions except the north,
- oilseeds were gradually increasing by 1.21% in the 1980s and by 2.34% in the 1990s; Groundnut is the major oilseed crop in the state, contributing to 94% of the total oil seed production and its yield increased by 3.2% annually in the 1990s,
- sugarcane, a prominent crop in the state, had no significant yield increases since 1980, and
- cotton increased by 4.2% in the 1980s and by 7.8% in the 1990s; the spreading of BT cotton has contributed to the sharp growth in yield in the latter period; this has contributed to increase cotton production by 42% between 1990 and 2000, although area under cotton declined by 36% over the same period.

Declining productivity and crop area have had a severe effect on the state's situation in food-grain security. Supply of food grain in 2004-05 was only 65% of the demand, in comparison to 96% in 2000. Importantly, rice production has dropped drastically, 31% over this period, accounting for only 61% of the demand in 2004.

Discussion of Future Scenarios

In this section, we discuss a few future scenarios emerging from recent trends or to explore in the irrigation sector in Tamil Nadu.

- The NSA of the state has been declining, and nonagricultural uses have taken up part of the decreased area. With rapidly increasing urban population and expanding industrial and service sectors, this trend is expected to continue.
- A part of the NSA area was also left fallow for an extended period of time. Increasing migration of agricultural labor to nonagriculture sectors, decreasing the agriculture-dependent population and increasing competition for water from other sectors could aggravate this situation. Although no visible trends exist at present, opportunities for land consolidation for increasing economies of scale in land use in agriculture could emerge in the future.
- With increasing competition for surface water from other sectors, maintaining area under major/medium irrigation schemes at the present level could be a serious challenge. It is likely that net irrigated area under major/medium irrigation would further decrease. And most of the surface irrigation under major/medium schemes will be confined to high productive and high potential areas. Moreover, as a solution to the declining irrigated area, changing operations of irrigation deliveries to increase adoption of water saving technologies or changing to low-water-intensive cropping patterns needs to be explored.
- Increasing variability of rainfall and unreliable surface irrigation supplies are major causes for declining tank irrigated area. Many small tanks cannot offer adequate irrigation supply for even a single season. Thus, command area under tanks will decrease further. However, many of these tanks can be used as water recharge structures for groundwater irrigation. They will provide a better control of on-farm water use in irrigation. Additionally, it will be a reliable drinking water supply for human beings and livestock in tank command

areas. Thus, it is likely that groundwater irrigation will increase in the tank command areas.

- In spite of the declining water tables, the number of dug wells and tube wells in most regions are increasing, albeit at a slower rate. Groundwater irrigation has better control of water use and can, in turn, contribute to higher crop productivity than surface irrigation. Augmenting groundwater supply for maintaining or expanding groundwater irrigation should be a key plank of the state water policy. Artificial groundwater recharge should be promoted to the extent where there is no impact on downstream water users. These will have major spatial distributional impacts on agriculture-dependent livelihoods.
- Micro-irrigation techniques improve water-use efficiency, reduce irrigation demand and improve crop productivity. Yet, only about 66,000 ha of cropped area use drip and sprinkler irrigation (Narayanamoorthy 2009), which is only 4% of the net area under groundwater irrigation. In general, groundwater irrigation is conducive to adopting micro-irrigation. Groundwater is the source for a large part of irrigated area of non-grain crops such as vegetables, fruits and sugarcane. These crops and areas have the largest potential for adopting drip and sprinkler irrigation in India.
- Decreasing per capita demand, water scarcities and low prices are major reasons for decreasing paddy area. Paddy area seemed to have stabilized at around 2 million ha, and most of that are irrigated. Providing a reliable irrigation supply to support paddy growing in this area will be a key challenge. Water saving techniques, such as system of rice intensification (SRI) or aerobic rice (AR), reduce the irrigation demand and, in most cases, improve crop productivity. With increasing water scarcities, the demand for introducing water saving techniques in paddy cultivation will increase.
- Food demand for coarse cereals is decreasing. Thus, the area under other cereals is also decreasing. This trend will likely continue into the future.
- Demand for feed crops, such as maize, has increased sharply. The total and irrigated maize area have had a sixfold and fourfold increase, respectively, since 1990. Maize area will expand further, and much of that expansion will take place in areas under other coarse cereals. Thus, additional water demand for increasing maize production could be marginal.
- Sugarcane area, with most of it under irrigation, has increased until 2000 and declined sharply since then. Even this area has a significant production surplus now. Whether this decline is a blip in the cropping pattern or a continuous trend is not exactly clear.
- Although area under cotton is declining, its production is gradually increasing. Adoption of high-yielding varieties, such as BT cotton, could be the main driver for yield growth. This trend is likely to continue into the future.

Annex Table 1. Land-use patterns at agroclimatic subregional level.

Year	Agroclimatic subregions						Agroclimatic subregions					
	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu
	Net sown area (1,000 ha)						Net irrigated area (1,000 ha)					
1970-1971	817	2,104	1,474	617	1,107	6,257	182	711	813	512	399	2,649
1974-1976	812	1,925	1,401	600	971	5,850	171	669	813	501	363	2,545
1979-1981	771	1,916	1,314	614	1,023	5,777	206	822	781	511	415	2,763
1984-1986	796	1,884	1,362	586	903	5,674	171	713	770	492	335	2,509
1989-1991	849	1,851	1,318	565	918	5,656	232	712	680	475	363	2,492
1994-1996	875	1,752	1,394	549	811	5,539	277	762	825	428	339	2,662
1999-2001	846	1,613	1,282	504	753	5,154	313	816	839	446	344	2,787
2004-2005	480	1,531	1,095	662	848	4,770	255	773	824	429	356	2,667
	Nonagricultural use area (1,000 ha)						Forest area (1,000 ha)					
1970-1971	153	404	395	192	332	1,499	480	746	418	14	178	1,992
1974-1976	146	476	417	180	378	1,629	475	724	412	18	181	1,980
1979-1981	113	509	467	188	417	1,726	494	714	412	19	186	2,024
1984-1986	114	521	502	191	419	1,780	496	745	426	19	184	2,069
1989-1991	118	534	523	195	420	1,824	535	777	431	19	193	2,153
1994-1996	126	556	551	200	431	1,898	543	764	431	19	191	2,146
1999-2001	134	616	601	162	440	1,987	538	772	431	10	185	2,134
2004-2005	188	654	637	166	449	2,132	536	762	431	10	185	2,120
	Current fallow area (1,000 ha)						Other than current fallow area (1,000 ha)					
1970-1971	101	370	160	25	253	913	44	172	128	22	186	557
1974-1976	131	647	279	48	342	1,452	39	136	111	30	236	557
1976-1981	192	727	362	41	369	1,707	36	98	97	20	200	457
1984-1986	140	606	314	59	347	1,482	63	241	114	30	340	794
1989-1991	89	640	328	50	238	1,357	44	220	139	54	401	868

1994-1996	74	637	215	39	230	1,207	30	269	197	69	457	1,030
1999-2001	92	610	266	20	213	1,209	36	317	235	46	492	1,132
2004-2005	124	411	285	20	70	917	44	415	260	60	566	1,349
	Permanent pasture and grazing land (1,000 ha)						Barren land (1,000 ha)					
1970-1971	27	76	75	6	36	230	161	178	284	32	111	819
1974-1976	26	65	58	5	27	189	149	152	233	36	63	663
1979-1981	26	48	47	6	24	159	140	139	208	39	52	588
1984-1986	26	38	44	6	25	145	132	137	183	39	56	556
1989-1991	26	31	38	5	19	124	113	129	167	36	59	510
1994-1996	27	30	41	5	18	125	110	118	156	39	60	490
1999-2001	41	90	100	23	115	377	110	119	143	36	62	476
2004-2005	46	102	96	22	122	396	110	147	142	36	64	506

Note: Hill and south regions have only 3% of NSA; 1% of NIA; 2% of nonagricultural use land, and less than 1% of the current fallow, other than current fallow, permanent pasture and grazing land, but 8% of forest area in 2005.

Annex Table 2. Total source-wise net irrigated area and as a percent of total NIA in agroclimatic subregions.

Year	Agroclimatic subregions						Agroclimatic subregions					
	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu
	Net canal irrigated area (1,000 ha)						Net canal irrigated area - % of total NIA					
1970-1971	25	267	98	474	23	907	14	38	12	93	6	34
1974-1976	20	254	104	461	22	875	12	38	13	92	6	34
1979-1981	25	282	96	470	22	907	12	34	12	92	5	33
1984-1986	24	249	78	448	20	830	14	35	10	91	6	33
1989-1991	25	265	62	417	22	801	11	37	9	88	6	32
1994-1996	26	264	63	384	21	770	9	35	8	90	6	29
1999-2001	30	265	69	425	21	822	10	32	8	95	6	29
2004-2005	15	245	60	399	27	762	6	32	7	93	7	29

	Net tank irrigated area (1,000 ha)						Net tank irrigated area - % of total NIA					
1970-1971	35	141	419	29	275	911	19	20	52	6	69	34
1974-1976	21	107	348	29	246	764	13	16	43	6	68	30
1979-1981	20	140	270	27	278	752	10	17	35	5	67	27
1984-1986	18	107	263	27	204	636	11	15	34	6	61	25
1989-1991	19	94	169	19	226	544	8	13	25	4	62	22
1994-1996	19	69	232	22	206	564	7	9	28	5	61	21
1999-2001	23	53	214	8	204	518	7	7	26	2	59	19
2004-2005	14	38	176	0	209	449	6	5	21	0	59	17
	Net dug-well irrigated area (1,000 ha)						Net dug-well irrigated area - % of total NIA					
1970-1971	120	286	264	8	99	778	66	40	33	2	25	29
1974-1976	125	300	281	8	94	808	73	45	35	2	26	32
1979-1981	157	390	296	7	113	963	76	47	38	1	27	35
1984-1986	126	344	324	8	109	912	74	48	42	2	32	36
1989-1991	183	332	318	10	114	959	79	47	47	2	31	38
1994-1996	222	399	383	8	110	1124	80	52	46	2	33	42
1999-2001	247	457	389	1	117	1214	79	56	46	0	34	44
2004-2005	197	419	377	1	116	1111	77	54	46	0	33	42
	Net tube-well irrigated area (1,000 ha)						Net tube-well irrigated area - % of total NIA					
1970-1971	0	6	14	0	0	20	0	1	2	0	0	1
1974-1976	0	3	60	1	0	65	0	0	7	0	0	3
1979-1981	0	4	105	4	1	114	0	1	13	1	0	4
1984-1986	0	6	95	8	1	110	0	1	12	2	0	4
1989-1991	2	15	126	28	2	173	1	2	19	6	0	7
1994-1996	7	24	144	12	1	188	2	3	17	3	0	7
1999-2001	11	31	163	11	2	218	3	4	19	3	1	8
2004-2005	24	68	207	29	4	332	9	9	25	7	1	12

	Net groundwater irrigated area (1,000 ha						Net groundwater irrigated area - % of total NIA					
1970-1971	120	292	278	8	99	798	66	41	34	2	25	30
1974-1976	125	303	341	10	94	873	73	45	42	2	26	34
1979-1981	157	395	401	10	113	1076	76	48	51	2	27	39
1984-1986	126	350	419	15	110	1022	74	49	54	3	33	41
1989-1991	185	347	445	38	115	1132	80	49	65	8	32	45
1994-1996	229	422	527	20	112	1312	83	55	64	5	33	49
1999-2001	258	488	552	13	119	1432	82	60	66	3	35	51
2004-2005	220	487	585	30	120	1443	86	63	71	7	34	54

Annex Table 3. Gross irrigated and cropped areas and irrigation and cropping intensity in agroclimatic subregions.

Year	Agroclimatic subregions						Agroclimatic subregions					
	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu
	Gross irrigated area (1,000 ha)						Irrigation intensity (%)					
1970-1971	233	902	1,126	663	482	3,472	128	127	138	130	121	131
1974-1976	214	841	1,051	603	398	3,158	126	126	130	120	110	124
1979-1981	278	1,034	1,030	673	504	3,570	136	126	131	132	121	129
1984-1986	242	827	1,078	619	389	3,203	141	116	140	126	116	127
1989-1991	298	849	936	547	415	3,096	128	119	138	115	114	124
1994-1996	392	896	1,089	555	384	3,363	144	118	132	130	113	126
1999-2001	403	842	1,022	554	360	3,226	129	103	122	124	105	116
2004-2005	332	821	912	428	456	2,983	131	106	111	100	128	112
	Gross cropped area (1,000 ha)						Cropping intensity (%)					
1970-1971	945	2,369	1,908	901	1,216	7,513	116	113	129	146	110	120
1974-1976	924	2,161	1,801	896	1,060	7,014	114	112	128	149	109	120
1979-1981	914	2,223	1,703	945	1,128	7,078	118	116	129	154	110	122
1984-1986	956	2,068	1,930	895	974	6,990	120	110	142	153	108	123

1989-1991	1,075	2,060	1,745	831	993	6,884	127	111	133	147	108	122
1994-1996	1,154	1,878	1,803	756	863	6,633	132	107	129	138	106	120
1999-2001	1,140	1,742	1,570	779	794	6,199	135	108	122	155	105	120
2004-2005	950	1,731	1,465	733	886	5,932	198	113	134	111	104	124

	Grain crop area (1,000 ha)						Irrigated grain crop area (1,000 ha)					
1970-1971	565	1,384	1,238	747	692	4,698	164	608	939	630	381	2,784
1974-1976	539	1,353	1,137	738	584	4,414	130	562	860	573	308	2,484
1979-1981	524	1,319	1,079	804	670	4,450	154	609	798	637	379	2,625
1984-1986	524	1,212	1,179	741	515	4,218	109	448	786	575	281	2,239
1989-1991	557	1,069	959	679	565	3,877	140	433	603	479	294	1,991
1994-1996	533	925	1,008	629	505	3,640	170	438	744	504	269	2,159
1999-2001	481	820	894	687	460	3,377	160	381	665	514	251	1,999
2004-2005	462	835	813	618	530	3,286	263	412	655	376	349	2,077

	Non-grain crop area (1,000 ha)						Irrigated no-grain crop area (1,000 ha)					
1970-1971	380	985	670	154	524	2,815	69	294	187	33	101	687
1974-1976	385	808	663	158	476	2,600	83	278	191	30	90	675
1979-1981	390	905	623	141	458	2,628	124	425	232	36	124	945
1984-1986	432	855	751	155	459	2,772	133	379	292	44	108	964
1989-1991	518	991	786	152	428	3,008	159	416	333	67	121	1105
1994-1996	622	953	795	127	358	2,993	222	457	346	51	115	1205
1999-2001	659	922	676	93	334	2,822	243	462	358	41	110	1226
2004-2005	488	896	652	115	355	2,646	69	409	257	51	107	906

Annex Table 4. Total crop and irrigated areas of rice, maize, other cereals and pulses in agroclimatic subregions.

Year	Agroclimatic subregions						Agroclimatic subregions					
	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu
	Paddy area (1,000 ha)						Paddy irrigated area (1,000 ha)					
1970-1971	122	479	940	653	405	2,665	122	457	865	625	325	2,456
1974-1976	104	446	850	614	331	2,397	89	422	782	568	254	2,164
1979-1981	116	514	790	657	445	2,573	116	475	741	634	347	2,362
1984-1986	87	391	815	579	327	2,243	82	373	747	572	258	2,073
1989-1991	102	387	620	493	387	2,034	101	375	573	477	279	1,847
1994-1996	127	398	748	517	353	2,181	127	391	727	503	261	2,044
1999-2001	123	344	660	528	331	2,018	123	328	639	514	241	1,874
2004-2005	216	296	644	466	350	1,994	216	217	627	376	324	1,782
	Maize area (1,000 ha)						Maize irrigated area (1,000 ha)					
1970-1971	1	10	0	3	0	14	1	9	0	2	0	11
1974-1976	1	14	1	5	0	20	1	12	0	4	0	16
1979-1981	1	17	2	2	0	23	0	14	1	1	0	17
1984-1986	2	19	1	2	1	25	1	12	0	2	0	16
1989-1991	2	30	1	1	1	34	1	15	0	1	0	18
1994-1996	3	39	0	0	5	47	2	23	0	0	1	27
1999-2001	6	56	1	0	17	81	2	30	1	0	4	37
2004-2005	17	146	8	1	23	196	7	61	5	1	7	80
	Other cereal area (1,000 ha)						Other cereal irrigated area (1,000 ha)					
1970-1971	324	714	226	5	209	1,480	41	143	74	3	56	317
1974-1976	326	729	233	7	205	1,502	41	129	77	2	54	303
1979-1981	284	621	210	4	158	1,279	38	119	56	1	32	247
1984-1986	282	638	239	5	126	1,290	26	62	39	1	22	150
1989-1991	258	459	189	3	85	994	37	43	30	1	15	126
1994-1996	182	326	132	1	58	699	41	25	16	0	6	88
1999-2001	144	289	105	0	56	595	35	23	24	0	5	88
2004-2005	151	272	57	0	58	541	40	22	24	0	3	88

	Pulses area (1,000 ha)						Pulses irrigated area (1,000 ha)					
1970-1971	117	182	72	86	78	539	1	6	1	0	5	13
1974-1976	108	164	54	113	48	493	1	4	2	0	2	9
1979-1981	123	165	77	141	66	574	1	7	3	0	3	14
1984-1986	152	165	124	155	62	660	4	7	9	0	3	24
1989-1991	195	193	148	181	93	815	11	18	10	6	6	52
1994-1996	221	162	128	111	89	713	32	42	17	15	8	114
1999-2001	207	130	128	158	57	684	21	9	19	2	2	54
2004-2005	78	120	104	152	100	554	0	6	15	3	2	26

Annex Table 5. Total crop and irrigated areas of rice, maize, other cereals and pulses in agroclimatic subregions.

Year	Agroclimatic subregions						Agroclimatic subregions					
	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu
	Oilseed area (1,000 ha)						Oilseed irrigated area (1,000 ha)					
1970-1971	192	426	487	70	90	1280	11	56	116	15	9	206
1974-1976	196	325	468	78	70	1157	13	45	97	12	7	173
1979-1981	189	369	435	83	71	1165	20	116	123	15	10	284
1984-1986	233	371	526	93	88	1330	22	86	148	18	11	286
1989-1991	242	426	516	99	103	1405	32	104	155	23	13	328
1994-1996	314	411	481	75	88	1390	48	103	158	11	8	328
1999-2001	259	377	340	55	82	1136	59	78	129	8	6	279
2004-2005	163	373	339	57	89	1045	5	55	95	14	16	186
	Fruits/vegetable area (1,000 ha)						Fruits/vegetable irrigated area (1,000 ha)					
1970-1971	38	86	41	17	24	243	24	41	8	6	16	98
1974-1976	47	94	47	13	26	257	26	43	13	6	17	108
1979-1981	54	115	53	16	28	296	36	65	19	6	20	148
1984-1986	55	111	60	16	31	301	33	59	23	6	19	143
1989-1991	86	129	74	16	32	363	37	66	33	6	24	171
1994-1996	105	149	79	14	39	413	49	96	41	7	32	230

1999-2001	144	206	95	12	51	534	69	113	41	6	38	275
2004-2005	142	207	119	13	54	562	16	100	44	6	44	216
	Sugarcane area (1,000 ha)						Sugarcane area (1,000 ha)					
1970-1971	14	44	47	6	5	116	14	44	47	6	5	115
1974-1976	24	56	59	7	6	152	22	53	59	7	6	147
1979-1981	26	73	65	11	8	183	26	71	61	8	7	173
1984-1986	31	64	90	11	8	203	26	63	76	11	6	182
1989-1991	26	70	103	25	13	238	26	69	100	23	13	230
1994-1996	40	89	137	23	15	305	24	89	87	8	8	216
1999-2001	44	98	141	18	18	320	41	98	140	17	14	310
2004-2005	34	79	128	21	24	289	18	69	80	16	21	203
	Cotton area (1,000 ha)						Cotton irrigated area (1,000 ha)					
1970-1971	21	141	4	1	150	317	8	74	1	0	20	104
1974-1976	16	112	7	1	127	262	7	61	4	0	15	87
1979-1981	26	94	8	2	120	248	18	52	6	1	34	112
1984-1986	23	83	16	5	111	239	18	53	12	4	20	107
1989-1991	31	79	15	5	126	255	18	37	10	5	23	92
1994-1996	45	98	29	5	81	257	21	36	9	5	16	86
1999-2001	31	74	16	5	45	170	17	22	6	5	12	61
2004-2005	28	39	13	8	33	120	9	15	4	7	9	43
	Other non-grain crop area (1,000 ha)						Other non-grain crop irrigated area (1,000 ha)					
1970-1971	114	287	92	60	256	859	13	79	14	6	51	164
1974-1976	102	221	83	59	247	772	16	76	19	5	44	160
1979-1981	95	253	62	30	232	736	25	121	23	5	53	228
1984-1986	89	227	59	29	222	699	34	117	34	5	51	246
1989-1991	133	289	77	8	154	747	46	141	35	10	47	283
1994-1996	119	206	69	10	135	629	81	133	52	20	52	345
1999-2001	180	168	83	3	139	662	58	151	42	5	39	302
2004-2005	121	198	52	17	155	631	21	170	34	9	18	257

Annex Table 6. Crop yields of major crops in agroclimatic subregions (tons/ha).

Year	Agroclimatic subregions						Agroclimatic subregions					
	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu	North	Central	South-east coastal	Delta	North-east coastal	Tamil Nadu
	Paddy						Sorghum					
1970-1971	2.09	2.20	1.95	1.84	1.65	1.93	0.63	0.64	0.93	1.03	1.02	0.69
1974-1976	2.19	2.10	2.06	1.68	1.58	1.91	0.59	0.65	1.21	0.81	0.96	0.71
1979-1981	2.07	2.24	2.10	2.21	1.85	2.12	0.94	0.76	1.04	1.86	1.58	0.87
1984-1986	2.74	2.78	2.54	2.45	1.87	2.46	1.25	0.76	1.33	0.95	1.29	0.93
1989-1991	3.25	3.53	3.22	3.16	2.16	3.07	1.06	1.00	1.10	1.00	1.56	1.05
1994-1996	3.36	3.27	2.94	2.64	2.73	2.94	1.35	0.82	1.19	0.88	1.66	1.00
1999-2001	4.02	3.96	3.51	2.18	2.11	3.06	1.37	0.82	1.14		0.98	0.93
2004-2005	1.28	3.24	2.83	1.63	2.23	2.35	1.03	0.62	1.13		0.87	0.74
	Millet						Pulses					
1970-1971	0.85	0.69	0.96		0.73	0.79	0.14	0.27	0.23	0.18	0.18	0.21
1974-1976	0.91	0.92	1.34		0.69	0.96	0.23	0.28	0.37	0.29	0.26	0.28
1979-1981	1.19	0.99	1.28		1.05	1.12	0.33	0.32	0.35	0.20	0.27	0.29
1984-1986	1.29	1.01	1.46		1.10	1.24	0.48	0.46	0.43	0.36	0.34	0.42
1989-1991	1.87	1.11	1.36		1.38	1.44	0.44	0.37	0.47	0.42	0.47	0.43
1994-1996	1.99	0.96	1.30		1.47	1.48	0.46	0.35	0.42	0.32	0.29	0.39
1999-2001	1.98	1.02	1.66		1.67	1.68	0.53	0.39	0.43	0.21	0.74	0.43
2004-2005	1.34	1.02	1.39		1.54	1.33	0.38	0.37	0.42	0.14	0.58	0.35
	Oilseed						Groundnut					
1970-1971	0.97	0.91	0.99	0.62	0.67	0.91	1.11	1.07	1.07	0.92	0.97	1.06
1974-1976	0.73	0.77	1.05	0.66	0.49	0.84	0.83	0.91	1.12	0.99	0.82	0.99
1979-1981	0.83	0.97	0.93	0.65	0.55	0.87	1.20	1.31	1.14	1.22	1.17	1.21
1984-1986	0.95	0.92	1.03	0.72	0.68	0.93	1.09	1.11	1.21	1.02	0.99	1.14
1989-1991	1.10	0.90	1.18	0.65	0.58	0.98	1.30	1.21	1.29	1.28	0.96	1.25
1994-1996	1.32	1.03	1.50	0.67	0.60	1.20	1.64	1.40	1.66	1.47	1.33	1.57
1999-2001	1.36	1.06	1.70	0.40	0.63	1.24	1.80	1.39	1.98	1.69	1.59	1.72
2004-2005	0.99	1.05	1.55	0.51	0.65	1.12	1.37	1.43	1.81	2.10	1.71	1.60

	Sugarcane						Cotton					
1970-1971	78	105	79	84	91	90	0.34	0.32	0.34	0.43	0.38	0.35
1974-1976	92	98	106	101	89	100	0.23	0.31	0.28	0.37	0.43	0.36
1979-1981	126	89	100	73	68	96	0.27	0.30	0.32	0.35	0.81	0.54
1984-1986	102	111	103	92	99	105	0.41	0.40	0.45	0.48	0.96	0.68
1989-1991	111	109	98	114	111	105	0.29	0.31	0.39	0.37	1.32	0.82
1994-1996	105	118	100	87	91	104	0.30	0.27	0.29	0.30	0.72	0.42
1999-2001	102	119	97	82	95	103	1.87	1.82	1.81	1.36	1.48	1.73
2004-2005	95	106	102	79	49	96	b1.77	1.39	1.73	1.20	1.29	1.47

Sources of contribution to growth in crop production.

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Water Resources Management with Special Reference to Tank Irrigation with Groundwater Use

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Introduction

Tanks have existed in India from time immemorial and have been an important source of irrigation, especially in the southern peninsular. Kings, Zamindars and even the British rulers built many tanks in the eighteenth and nineteenth centuries. Though they are found in all parts of the country, tanks are concentrated in the southern states, such as Andhra Pradesh, Karnataka and Tamil Nadu, where they provided the largest source of irrigation until the mid-sixties. There are more than 39,000 tanks in Tamil Nadu state alone, with varying sizes and types and about 90% of them are rain-fed depending mainly on rainfall runoff for tank storage and irrigation. The area irrigated by tanks has been continuously declining from 0.9 to 0.5 million ha during the past 40 years and the share of the tanks in the total irrigated area has declined from 37% in the 1960s to 20% in the 2000s. Even though the share of tanks is decreasing part of it is replaced with groundwater irrigation in the tank command areas. Besides variation in rainfall and tank filling, several factors such as siltation, encroachment, and channel obstruction have reduced the tank irrigated area over the years. Also, over the years, increasing dug well irrigation in the tank commands has complicated the water allocation and management in the tanks (Palanisami and Easter 2000).

There are as many obstacles to tank irrigation as there are benefits, due to the large number of tanks and the differences in water demand, managerial experiences and investment needs for maintenance. In 2 out of 10 years the tank receives normal or excess rainfall; in 3 out of 10 years scanty rainfall results in tank failure; and in 5 out of 10 years deficit rainfall results in reduction of crop yields. Some tanks are reported to be functioning for irrigation only in normal/excess rainfall years and not so in poor/low-rainfall years. Since about 90% of the tanks are nonsystem or rain-fed the effect on area reduction will be more significant (Palanisami et al. 1997).

Over the years, farmers started supplementing tank water with well water, particularly in deficit years. There are tanks now acting as groundwater recharge ponds, and also meeting domestic and livestock water needs in the tank command areas where they use only groundwater. In about 10% of the tanks with adequate number of wells in the command area, the irrigated area has increased to 80%. However, due to constraints in the development of wells, the number of wells, for example, for every 4 ha, ranges from less than one to two wells, and the threshold level will be about one well for every 4 ha in a normal year, which will vary in different locations. In most cases, the tanks are having wells below the threshold level. It is also reported in a few cases that a larger number of wells above the threshold level will also affect the tank performance in terms of poor cooperation in operation and maintenance (O&M) of the tanks. In recent times, a major function of some tanks has changed from a primarily storage for surface irrigation to a groundwater recharge structure. However, these tanks do still play a major role in providing domestic water supply for humans and drinking water supply for the livestock population. Farmers, especially the rich and powerful, in the command area of these tanks now use dug wells or tube wells to irrigate their lands. Thus changing water use patterns in the command area of these tanks requires completely different management options.

It is felt that wells will be an integral part of the tank systems in the future and further research is needed to identify the role of tanks in providing water supply for different needs, and to assess the required supporting management structures and investment needs. Keeping this in mind, a detailed study was undertaken in Tamil Nadu, India with the following objectives.

- Study the implications (economic and hydrologic) of using tanks as percolation ponds and increasing groundwater irrigation in the tank command areas on the performance of tanks.
- Assess the groundwater recharge patterns with tanks as percolation ponds.
- Assess the threshold at which a tank can act as a groundwater recharge structure and provide water for domestic and livestock purposes while promoting groundwater irrigation in the tank command areas.
- Assess the management strategies of tanks and investment options for tank modernization under increasing groundwater irrigation in the tank command areas.

Methodology

Three districts in Tamil Nadu, Coimbatore, Madurai and Sivagangai, were selected to obtain the sample tanks for analysis. Ten tanks in each district were selected for the sampling. In each tank 25 households were randomly selected for this study. The sample for this study consists of 30 tanks and 750 households in those selected tanks. The purpose of selecting these districts was to get the equal distribution of sample households in the three different situations which are tank-only, tank-with-wells and wells-only. The 30 tanks selected randomly for this study were categorized into three different typologies such as tank-only, tank-with-wells, and wells-only. This categorization was based on the percentages of households depending on the type of water source under each tank (Table 1).

Table 1. Sample household distribution in the study area.

Typology	Tank-only	Tank-with-wells	Wells-only	Total
Tank-only	173 (23)	27 (3.6)	0	200 (27)
Tank-with-wells	54 (7.2)	246 (33)	0	300 (40)
Wells-only	0	0	250 (33)	250 (33)
Total	227 (30.3)	273 (36.4)	250 (33.3)	750 (100)

Note: Percentages of the total are given in parentheses.

If more than 80% of the households used a tank as the only source for irrigation, then this tank was categorized as typology I (the tank-only situation). If more than 80% of the households used only the wells as the source of irrigation in the tank area then this situation was categorized as typology III (wells-only situation) and the rest were grouped into typology II (tank-with-wells situation). In this study area, eight tanks in the Madurai District were categorized under typology I (i.e., the tank-only situation). It consists of 173 households which used tanks as the only source of water for irrigation. There were 27 households under those particular tanks that used tanks with wells as the sources of water for irrigation. Likewise, 12 tanks in Sivagangai and Madurai districts were categorized under typology II (i.e., the tank-with-wells situation). It consists of 246 households that used tanks-with-wells as the sources of water for irrigation. There were 54 households in typology II that used only the tank as the source of water for irrigation. Finally, 27 households in typology I and 54 households in typology II were excluded from the analysis except for partial budgeting because these households used the water source for irrigation that was different from the typological situation. This exclusion was made to draw the conclusions and recommendations based on the results obtained from each typological situation.

In the tank-only situation most of the households are marginal, accounting for 73% of the total number of households while the large farmers account for only 2% of the total number of households. In the tank-with-wells situation, nearly 45% are small farmers and around 18% large farmers. In the wells-only situation nearly 50% of the households are small households and around 28% large households (Table 2).

Table 2. Distribution of households (HH) and farm size in the three different situations.

	Distribution of HH					
	Tank-only		Tank-with-wells		Wells-only	
Farm size	No. of HH	% of total	No. of HH	% of total	No. of HH	% of total
No. of marginal households (< 1ha)	126	73	90	37	57	23
No. of small households (1-2 ha)	43	25	112	45	124	50
No. of large households (>2 ha)	4	2	44	18	69	28
Total no. of households	173	100	246	100	250	100

General Characteristics of the Sample Households

General characteristics of the sample households like age, education and landholdings of respondents, etc., were hypothesized to have significant influence on the adoption of new and improved technology and income of the respondents. The participation of the farmers in the tank and water management activities also depends on the socioeconomic characteristics.

Age of the Sample Respondents

Age is an important factor that affects various farm and tank management decisions. Hence, the age-wise distribution of the sample respondents is discussed below.

In the tank-only situation, nearly 32% are in the age group of 31-40 years followed by 29% of households in the age group of 41-50 years and 21% of households in the age group of 51-60 years. In the tank-with-wells situation around 38% belonged to the age group of 41-50 years, nearly 23% to the age group of 31-40 years, and approximately 21% to the age group of 51-60 years. In the wells-only situation, around 80% belonged to the age group of 31-50 years (Table 3).

In the tank-only situation, the majority are marginal farmers and a very few of them are large farmers. Around 94% of the marginal farmers and nearly 91% of the small farmers are in the age group of more than 30 years. In the tank-with-wells situation nearly 38% of the total households are in the age group of 41-50 years and many of them are marginal and small farmers. In the wells-only situation, nearly 40% belonged to the age group of 31-40 years followed by 39% belonging to the age group of 41-50 years. It can be concluded that most of the household heads are more than 31 years of age. This implies that these households might have enough experience in farming. In the tank-only and the tank-with-wells situations, less than 10% of the households are in the age group of 21-30 years and engaged in farming, and in the wells-only situation nearly 15% of the households are engaged in farming. This might be due to the migration of youngsters from villages to urban areas in search of alternative jobs and nonfarm activities.

Educational Status of the Sample Respondents

Education is an important variable that determines the access and adoption of technologies. Hence, data on the educational status of the respondents were collected and discussed concurrently.

Among the subgroups of households, the tank-only situation has the highest illiteracy rate compared to the other two groups of households. In the tank-only situation, around 28% of the sample households are illiterate. In the tank-with-wells and the wells-only situations, around 17% of the households in each group are illiterate. Among marginal households in the tank-only situation, the illiteracy rate is nearly 31%. In the tank-with-wells situation it is around 21%. In all three situations, more than 40% of the marginal farmers had 6-10 years of education. In the tank-with-wells and the wells-only situations more than 45% of the small farmers had 6-10 years of education. Among large farmers nearly 66% had 6-10 years of education (Table 3).

Table 3. Distribution of age and education in the study area.

	Tank-only				Tank-with-wells				Wells-only			
	Marginal farmers	Small farmers	Large farmers	Total	Marginal farmers	Small farmers	Large farmers	Total	Marginal farmers	Small farmers	Large farmers	Total
Age group (years)												
21-30	8	4	0	12	8	2	4	14	7	18	8	33
	(6.35)	(9.30)	(0.0)	(6.94)	(8.89)	(1.79)	(9.09)	(5.95)	(12.28)	(14.51)	(11.59)	(14.96)
31-40	43	13	0	55	22	25	9	56	22	47	32	101
	(34.13)	(30.23)	(0.0)	(31.79)	(24.44)	(22.32)	(20.45)	(22.70)	(38.60)	(37.9)	(46.38)	(40.16)
41-50	37	12	2	50	30	44	19	93	24	50	25	99
	(29.37)	(27.91)	(50.00)	(28.90)	(33.33)	(39.29)	(43.18)	(38.38)	(42.10)	(40.32)	(36.23)	(38.58)
51-60	25	10	1	37	18	24	11	53	4	9	4	17
	(19.84)	(23.26)	(25.00)	(21.39)	(20.00)	(21.43)	(25.00)	(21.08)	(7.02)	(7.26)	(5.80)	(6.30)
61-70	11	4	1	17	11	15	1	27	0	0	0	0
	(8.73)	(9.30)	(25.00)	(9.83)	(12.22)	(13.39)	(2.27)	(10.81)	(0.0)	(0.0)	(0.0)	(0.00)
71-80	2	0	0	2	1	2	0	3	0	0	0	0
	(1.59)	(0.0)	(0.0)	(1.16)	(1.11)	(1.79)	0.00	(1.08)	(0.0)	(0.0)	(0.0)	(0.00)
Total	126	43	4	173	90	112	44	236	57	124	69	250
Educational status												
Illiterate	39	8	0	88	19	18	4	31	13	21	9	43
	(30.95)	(18.60)	(0.00)	(28.30)	(21.116)	(16.07)	(9.09)	(16.76)	(24.14)	(16.67)	(2.86)	(17.32)
Primary	25	13	2	70	25	40	11	56	12	32	17	61
	(19.84)	(30.23)	(50.00)	(22.51)	(27.78)	(35.71)	(25.00)	(30.27)	(20.69)	(25.4)	(24.29)	(24.02)
Secondary	57	18	1	137	38	50	29	89	26	65	33	124
	(45.24)	(41.86)	(25.00)	(44.05)	(42.22)	(44.64)	(65.90)	(48.11)	(44.83)	(53.17)	(48.57)	(50.00)
Plus 1	5	3	1	15	7	4	0	8	4	5	8	17
	(3.97)	(6.98)	(25.00)	(4.82)	(7.78)	(3.57)	(0.0)	(4.32)	(6.90)	(3.97)	(11.43)	(6.69)
College	0	1	0	1	1	0	0	1	2	1	2	5
Total	126	43	4	173	90	112	44	246	57	124	69	250

In the sample as a whole, the number of farmers with 6-10 years of education was greater in the tank-with-wells and the wells-only situations accounting for nearly 48% and 50%, respectively, whereas in the tank-only situation, the illiteracy rate and the proportion of households were 1-5 years of education and around 50%, respectively.

The educational status showed that nearly 22% of the households were illiterate. Further, most of the literates had less than 10 years of schooling. Hence, necessary effort should be taken to educate the farmers on the new technology developed in the agriculture sector.

Cropping Pattern

In the sample, in the tank-only situation, around 84% of the households cultivated only one crop per year and about 16% two crops per year. The source of water supply is the tank for the first crop and rain for the second crop. Among the households cultivating two crops per year, nearly 43% are large farmers. In the tank-with-wells situation, around 67% of the households cultivated two crops a year, 32% only one crop a year and 1% three crops a year. In the wells-only situation, around 84% of the households cultivated two crops a year, 16% only one crop a year and 2% three crops a year. Clearly, this shows the availability of water in different situations. The analysis shows that in all three situations most of the small and large farmers cultivated two crops a year and the level of supplemental irrigation influenced the cropping pattern.

In the tank-only situation, 99% of the farmers cultivated only paddy. In the tank-with-wells situation, nearly 75% were involved in paddy cultivation and around 53% in sugarcane cultivation. The percentage of households involved in coconut, cotton and banana were 15, 11 and 4, respectively. In the wells-only situation 45% of the households were involved in cultivating banana, 41% in sugarcane, 43% in coconut, 32% in sorghum (rain-fed) and 8% in maize while a very few of them (less than 4% of the households) were involved in cultivating Bengal gram, turmeric, curry leaves and onion. This indicates that in the wells-only situation most of the households cultivated high-value crops as there is less risk in the supply of water through well irrigation, and in the tank-with-wells situation a considerable number of farmers diverted their cultivation pattern towards high-value crops.

Productivity

Productivity refers to the yield per unit area of land. Table 4 indicates that the productivity of the same crop varies with different typologies. The source of water supply is an important factor that decides crop productivity. Productivity of paddy is higher in the tank-with-wells situation than in the tank-only situation. Likewise, the productivity of sugarcane is nearly 8.6 tons/ha higher in the wells-only situation than in the tank-with-wells situation.

Income of the Sample Respondents

The average income per ha of the tank-only farmers from crop cultivation was Rs 17,599 whereas it was Rs 46,993 in the tank-with-wells situation and Rs 117,365 in the wells-only situation (Table 5). The income from agricultural crops alone contributed nearly 24%, 50% and 80% of the total income of the farmers in the tank-only, the tank-with-wells, and the wells-only situations, respectively. The contribution of income from nonagriculture was 27% in the tank-only situation whereas it was 26% in the tank-with-wells situation and 9% in the wells-only situation. The income from off-farm work contributed 16% in the tank-only, 11% in the tank-with-wells and 6% in the wells-only situations. The income from livestock contributed 17% of the total income in the tank-only situation. In the tank-with-wells and the wells-only situations the corresponding proportions were only 7% and 1.5%, respectively. The contribution of tree resources to the total income of farmers was less than 8% in all three situations.

In the tank-with-wells situation, all three categories of farmers (marginal, small and large) received more than double the income of what they received in the tank-only situation from agricultural crops alone. Similarly, the farmers in the wells-only situation earned more than double the income of what they earned in the tank-with-wells situation from crop cultivation. Table 4 shows that the income is increasing with assured water supply.

In the wells-only situation, farmers cultivated high-value crops as there was minimal risk in water supply. This is the reason for getting a higher income. But in the tank-with-wells situation, the majority of the farmers cultivated rice as the first crop and high-value crops as their second choice. This is the reason for getting a considerably lower income in the tank-with-wells situation compared to the wells-only situation.

From the above discussion, it could be concluded that agricultural crops were the main source of income among the selected farmers in all the situations. Further, a significant portion of the income was also from the nonfarm and off-farm activities. But in the tank-only situation, contribution of income from nonfarm activities was slightly higher than that from crop cultivation. It is necessary to strengthen the source of water supply to promote their major income source of crop cultivation.

Tank Performance and Management

The characteristics of the farmers have an influence on the overall performance of the tanks through farmers' involvement in tank management. Table 6 summarizes the participation of farmers in tank-management activities. It shows that the farmers in the tank-with-wells situation had participated comparatively less in tank management than in the tank-only situation. Farmers normally contributed labor, gunny bags and money for tank management. The average period of participation was only 1 to 2 days. In the wells-only situation, participation in tank management was very poor (Table 6).

For the sample as a whole, the number of farmers who contributed their labor for tank management was comparatively higher in the tank-only situation (69.9%) than in the tank-with-wells situation (22.3%). In contrast, the money contributed by the farmers for tank management activities was higher in the tank-with-wells situation (43.0%) than in the tank-only situation (27.2%), indicating that farmers felt the importance of tanks in crop production.

Water Management

Next to tank management activities, farmers' participation in water management was considered important, since in most of the years the tanks used to get below-normal supplies. Hence, an analysis of water management among the tanks in different typologies was done (Table 7).

Table 4. Productivity of different crops in different typologies.

Crop	Tank				Tank-with-wells				Wells-only			
	Marginal	Small	Large	Total	Marginal	Small	Large	Total	Marginal	Small	Large	Total
Paddy (kg/ha)	4,832	4,910	4,999	4,856	4,897	5,616	5,850	5,063	-	-	-	-
Sugarcane (kg/ha)	-	-	-	-	91,425	95,300	97,525	96,635	104,525	106,375	102,500	105,315
Banana (bunches/ha)	-	-	-	-	-	1,800	1,875	1,812	2,004	1,895	2,500	1,970
Coconut (nuts/ha)	-	-	-	-	15,370	16,135	16,417	15,694	16,594	17,511	17,317	16,931
Cotton (quintal/ha)	11.47	12	10	12.24	-	17.07	18.42	17.62	-	-	-	-

Source: Based on the primary survey.

Table 5. Income details of the farmers with different farm sizes in different typologies.

Income source	Tank				Tank-with-wells				Wells-only			
	Marginal	Small	Large	Total	Marginal	Small	Large	Total	Marginal	Small	Large	Total
From crops (Rs/ha)	17,373		20,625	17,599	36,210	54,733	53,055	46,933	98,264	119,648	132,642	117,366
Off-farm income	12,079		10,000	11,825	9,208	15,333	-	10,433	4,000	15,000	-	8,500
Nonfarm income	18,403		40,500	19,266	21,214	16,231	86,667	24,069	13,693	12,063	18,444	12,997
Livestock	12,750		-	12,020	6,136	5,820	7,500	6,117	-	-	-	-
Poultry	5,000	-	-	5,000	-	-	-	-	-	2,500	-	2,333
Tree	-	-	6,500	6,500	-	4,000	9,000	5,666	4,000	6,091	64,839	6,317

Source: Based on the primary survey.

Table 6. Participation in tank management in different irrigation typologies.

Particulars	Tank-only				Tank-with-wells				Wells-only			
	Marginal	Small	Large	Total	Marginal	Small	Large	Total	Marginal	Small	Large	Total
No of farmers who participated	121	43	4	168	18	100	43	161	0	11	15	26
	(98.4)	(97.7)	(66.7)	(97.1)	(20.0)	(89.3)	(97.7)	(65.4)	(0.0)	(8.9)	(21.7)	(10.4)
Labor contribution												
No. of farmers	90	30	1	121	4	43	8	55	0	11	15	26
	(73.2)	(68.2)	(16.7)	(69.9)	(4.4)	(38.4)	(18.2)	(22.4)	0	(8.9)	(12.1)	(21.0)
Average no. of days	2.5	2.3	1.9	1.75	2.1	1.69	1.66	1.68	-	3.86	3.77	3.8
Money contribution												
No. of farmers	31	13	3	47	14	57	35	106	-	-	-	-
	(25.2)	(29.6)	(50.0)	(27.2)	(15.6)	(50.9)	(79.6)	(43.1)	-	-	-	-
Average contribution (Rs/ha)	50	50	50	50	50	50	50	50	-	-	-	
Total no. of farmers	123	44	6	173	90	112	44	246	57	124	69	250

Notes: Numbers within parentheses are percentages of the total number of farmers.

Source: Based on the primary survey.

Table 7. Participation in water management in different irrigation typologies.

Particulars	Tank-only				Tank-with-wells				Wells-only			
	Marginal	Small	Large	Total	Marginal	Small	Large	Total	Marginal	Small	Large	Total
No of farmers who participated	97	36	5	138	24	97	38	159	-	6	13	19
	(78.9)	(81.8)	(83.3)	(79.8)	(26.7)	(86.6)	(86.4)	(64.6)	-	(4.8)	(18.8)	(7.6)
Labor contribution												
No. of farmers	64	23	3	90	6	41	6	53	-	6	13	19
	(52.0)	(52.3)	(50.0)	(52.0)	(6.7)	(36.6)	(13.6)	(21.5)	-	(4.8)	(18.8)	(7.6)
Average no. of days	1.21	1.43	1.72	1.26	1.27	1.22	1.19	1.22				
Money contribution												
No. of farmers	33	13	2	48	18	56	32	106	-	-	-	-
	(26.8)	(29.5)	(33.3)	(27.7)	(20.0)	(50.0)	(72.7)	(43.1)	-	-	-	-
Average contribution (Rs/ha)	342.5	360	375	347.5	247	306.6.	343.7	311.6	-	-	-	-
Total no. of farmers	123	44	6	173	90	112	44	246	57	124	69	250

Notes: Numbers within parentheses are percentages of the total number of farmers.

Source: Based on the primary survey.

Scope of Converting Tanks into Percolation Tanks

Over the years, tanks have been converted into percolation tanks for the following reasons:

1. Conflicts in the distribution of tank water between the head- and tail-end farmers
2. Inadequate tank supplies due to poor tank storage.
3. A larger number of wells in the tank command area compared to the threshold level.
4. Interest of the farmers in growing annual crops which require water supplies throughout the year.

In the case of the three typologies, total production was comparatively high in the wells-only situation followed by the tank-and-wells situation, where the additional gross income and the net income were comparatively higher (Table 8). Water productivity was also higher in the wells-only situation followed by the tank-and-wells situation. Hence, conversion of tanks into percolation ponds was justified, even though farmers who did not have wells had to depend on the well owners for their irrigation needs. The additional cost of pumping with electricity was also higher in the wells-only situation. However, it was financially justifiable to invest in wells where possibilities for conversion of tanks existed due to the above-mentioned reasons.

Table 8. Total value of production with different typologies.

Typology	Total value of production	Total income	Additional income	Cost of cultivation	Net income	Additional net income
	Rs	Rs/ha	Rs/ha	Rs/ha	Rs/ha	Rs/ha
Tank-only	2,344,490	28,343	0	17,589	10,754	0
Tank-with-wells	13,049,154	71,406	43,063	38,719	32,687	21,933
Wells-only	2,656,928	106,582	78,238	57,505	49,076	38,322

The total income and cost of cultivation are computed using the weighted average of income and cost, respectively. The cost of irrigation was also included in the cost of cultivation. The average area per well was 2 ha in the wells-only situation, 10 ha in the tank-only situation, and 4 ha in the tank-and-wells situation (Tables 9, 10 and 11).

Table 9. Threshold level of wells in the wells-only situation.

Tank no.	Total no. of wells in ayacut	Ayacut area (ha)	No. of wells per ha	Area per well (ha)	Threshold level
1	25	60.00	0.42	1.6	Above optimum
2	21	51.77	0.41	1.52	Above optimum
3	24	43.60	0.55	0.89	Above optimum
4	22	23.20	0.95	0.56	Above optimum
5	200	208.80	0.96	0.5	Above optimum
6	22	48.40	0.45	0.91	Above optimum
7	26	46.80	0.56	0.97	Above optimum
8	32	59.15	0.54	1	Above optimum
9	2	8.00	0.25	4	Below optimum
10	4	10.00	0.40	2.5	Below optimum
Average			0.55		One well in 2 ha

Table 10. Threshold number of wells in the tank-only situation.

Tank no.	Total number of wells in ayacut	Ayacut area (ha)	Number of wells per ha	Area per well (ha)	Threshold level
1	8	46.18	0.17	6	Above optimum
2	4	146.65	0.03	42	Below optimum
3	6	47.05	0.13	8	Above optimum
4	4	29.86	0.13	7	Above optimum
5	4	42.00	0.10	11	Below optimum
6	4	24.00	0.17	6	Above optimum
7	6	66.00	0.09	11	Below optimum
8	7	518.32	0.01	74	Below optimum
Average			0.10		One well in 10 ha

Table 11. Threshold level of wells in the tank-and-wells situation.

Tank no.	Total no. of wells in ayacut	Ayacut area (ha)	No. of wells per ha	Area per well (ha)	Threshold level
1	15	131.23	0.11	9	Below optimum
2	15	36.13	0.42	2	Above optimum
3	45	115.33	0.39	3	Above optimum
4	38	414.5	0.09	11	Below optimum
5	70	744.48	0.09	11	Below optimum
6	45	343.22	0.13	8	Below optimum
7	52	260.44	0.20	5	Below optimum
8	32	447.56	0.07	14	Below optimum
9	20	26.4	0.76	1	Above optimum
10	15	48.58	0.31	3	Above optimum
11	35	222.51	0.16	6	Below optimum
12	20	43.29	0.46	2	Above optimum
Average	33.5		0.27		One well in 4 ha

Groundwater Use in Tank Irrigation

Water purchase, sales and its price show the scarcity and the details could explain the nature of water sales and the extent of water scarcity in the study region (Table 13). Out of the total number of farmers selected for the study, 26 and 27 farmers were water buyers in the tank-with-wells and the wells-only situations, respectively. Among the water buyers, marginal, small and large farmers and the price paid per pumping hour are shown in Table 12.

Table 12. Details of water buyers in the tank-with-wells and the wells-only typologies.

Particulars	Tank-with-wells		Wells-only	
	No. of farmers purchasing water	Price Rs/hr	No. of farmers purchasing water	Price Rs/hr
Marginal farmers	3	10	0	-
Small farmers	20	16.81	13	23.26
Large farmers	3	35	14	29.7
Total	26		27	

Price per pumping hour differs with locations of the wells, their depths and the monopolistic behavior of the well owner. It ranged from Rs 10 per pumping hour to Rs 50 in the study area. The majority of the large farmers owned wells. A few of them did not own wells. As they were large farmers, the well owners would fix a higher rate for them and also due to the location of lands, the farmers paid a higher rate for a pumping hour in the study area.

Yield and Input Use

Paddy was the main crop in the tank-only and the tank-with-wells situations but paddy was not cultivated in the wells-only situation. Paddy performs better in the tank-with-wells situation compared to the tank-only situation (Table 13). Input use is also less when compared to the tank-only situation except in the case of farmyard manure.

Farmers cultivated sugarcane in the tank-with-wells and the wells-only situations. The yield of sugarcane was nearly 8.6 tons/ha higher in the wells-only situation compared to the tank-with-wells situation (Table 14). Except for human and machine labor other inputs were used more in the tank-with-wells situation compared to the wells-only situation. The higher yield in the wells-only situation may be due to more frequent usage of human and machine labor besides better water control.

Table 13. Yield and input use in different typologies – paddy crop.

Typology	Yield	Input use						
		Seed	NPK	Human labor	Machine labor	*Water	Chemicals	Farm manure
	kg/ha	kg/ha	kg/ha	man-days /ha	hours/ha	m^3/ha	No. of sprays	(tons/ha)
Tank-only	4,899	94.90	293.35	71.00	11.35	9,469	2.00	3.00
Tank-with-wells	5,063	85.38	289.13	65.69	9.94	7,956	1.39	3.50
Wells-only	-	-	-	-	-	-	-	-

*Water used excluding rainfall is given. The average rainfall received during the crop season was about 645 mm.

Table 14. Yield and input use in different typologies – sugarcane crop.

Typology	Yield	Input use Seed	NPK	Human labor	Machine labor	Water	Farm manure
	kg/ha	kg/ha	kg/ha	man-days/ha	hours/ha	m^3/ha	tons/ha
Tank-only	96,635	74,868	370	120.1	6.0	9,294	8.2
Tank-with-wells	105,475	71,775	337	196.4	9.9	7,613	6
Wells-only	96,635	74,868	370	120.1	6.0	9,294	8.2

In the tank-with-wells situation, 27 households depended only on tanks as the sole source of water supply. The supplemental irrigation along with other inputs contributed to the yield (Table 15). Farmers in the study area used up to eight supplemental irrigations. The yield was continuously increasing with the number of irrigations with increased use of human labor and NPK fertilizer. As the other inputs did not change much with the increase in the number of supplemental irrigations, the other input quantities are not displayed in Table 15. Further, the increase in yield was more when the number of supplemental irrigations was two. It reveals that at least two supplemental well-irrigations appear to be important for the rice crop since irrigation generally occurs during the reproductive stage of the rice crop. Water stress at this stage has a tremendous adverse effect on yield. The yield increase was more than 956 kg/ha for the second supplemental irrigation. The application of NPK fertilizer moved up to four supplemental irrigations and then it declined. Use of human labor was increasing or was stable with the use of supplemental irrigation.

Table 15. Change in yield and input use with change in supplemental irrigation – paddy crop.

Number of supplemental irrigations	Yield (kg/ha)	NPK fertilizer (kg/ha)	Human labor (man-days/ha)
0	4,970	234	59
1	5,277	271	62
2	5,926	286	68
3	5,674	299	72
4	5,383	300	73
5	5,294	274	75
6	5,087	264	74
8	5,056	258	76

Cost of Pumping

The annualized cost of wells was computed to find out the average cost of irrigation in the tank-with-wells and the wells-only situations. The cost of irrigation depended on the type of well (dug well, dug-cum-bore well, tube well), current status of the well, year of construction, average age or life of the well and the discount rate. The cost of the electric motor and the annual repair charges were also included for the computation of annualized cost of irrigation.

Cost Calculation

Capital cost = Rs C

$Capital\ recovery\ factor\ (CRF) = \frac{i(1+i)^n}{(1+i)^n - 1}$, where, n is the life of the well in years and i is the bank interest rate.

Annualized cost (A)= Rs C * CRF

Other costs (Repair + labor cost) = Rs OC

Total cost = Rs. A+OC

This calculation was done separately for tank-with-wells and wells-only situations. The average annualized cost of wells was higher in the wells-only situation than in the tank-with-wells situation (Table 16). Though the annual pumping hours was higher in the wells-only situation the average cost of pumping was also higher than in the tank-with-wells situation. This may be due to the greater depth of the water table in the wells-only situation, where most of the farmers have bore wells, dug-cum-bore wells and tube wells. The water table is very deep and the cost of construction is also high.

Table 16. Annualized cost and average cost of pumping hours in different typologies.

Typology	Average annualized cost	Average annual pumping hours[1]	Average cost/ pumping hour	Average price/ irrigation/ha[2]
Tank-with-wells	14,117	1,116	12.65	215.05
Wells-only	23,261	1,378	16.88	320.72

[1] The number of pumping hours was calculated from the survey data. During the survey, data on the pumping hours per day, hours of pumping per irrigation, and frequency of irrigation in a week were collected from the farmers. Based on these items of information the number of month-wise pumping hours was calculated from January to December, 2006/07 cropping year.

[2] For the sugarcane crop it takes about 17 hours to irrigate 1 ha in the tank-with-wells situation and 19 hours in the wells-only situation in the study area. The average cost per pumping was multiplied by the time taken to irrigate per ha of crop thus arriving at the average price per irrigation per ha.

Partial Budget

The partial budget is used to work out costs and returns of making relatively small changes in the existing farm practices. It is aimed at answering the question relating to financial losses and gains due to the proposed changes in the agricultural enterprise. The partial budget was worked out with the aim of comparing the financial gains and losses by cultivating paddy and sugarcane crops in the place of paddy only. In normal practice, a farmer in the tank-with-wells situation having 2 ha land preferred to cultivate 1 ha of paddy and 1 ha of sugarcane. The same farmer in the tank-only situation cultivated only paddy for 2 ha (Table 17).

Net change in income due to the cultivation of paddy and sugarcane in 1 ha each was Rs 11,624, over the cultivation of paddy in 2 ha in the tank-only situation. This is why farmers prefer to have sugarcane whenever they have access to well irrigation in the tank system. The rate of return for this change will be about 27%.

Table 18. Partial budget for cultivating 1 ha paddy and 1 ha sugarcane instead of cultivating 2 ha paddy

		Debit (A)		Credit (B)
I	*Added cost*		*Added return*	
i)	Seed	9,907	Gross income	54,252
ii)	Human labor	3,010		
iii)	Machine labor	10,640		
iv)	Manures and fertilizers	11,605		
v)	Irrigation	3,962		
vi)	Interest on working capital	3,503		
II	*Reduced return*	0	*Reduced cost*	0
		42,628		54,252

. Rate of return = (B-A)/A = 27.27%

Water Market

Optimum Use of Wells

When the source of irrigation is the tank-with-wells, it is important to find out the possibilities of digging more wells in the study area. Farmers with more than 2 ha of land, who are about 15% of the total number of farmers in the tank command area, have wells in the study area. As there are only a few well owners, they act like monopolists. Each well owner may be the only supplier of groundwater, at least for the group of farmers located around the well. Since the number of wells is limited in most tanks, monopolistic behavior is quite common. Well interference during pumping and recharge rates are reflected in water availability and price. Well owners maximize their profits with respect to the water supplies available and the likely demands. They cannot set the price and quantity independently since the price is determined by the supply and demand for water. Reduction in pumping (up to a certain level) can increase the water price resulting in a higher profit. However, the marginal cost of pumping is very low (as electricity is free of charge) and it only pays to reduce pumping in the range where demand is inelastic.

For different levels of water prices and varying pumping hours in the study area, it is important to know at what level of pumping and water price (Pp) well owners maximize their profit. Using the fitted inverse demand, and output and average cost (AC) functions, and solving the equations for well yield (WY).[1]

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[1] Gives the profit equation,

$$\Pi = (Pp * Qp) - (AC * Qp) - FC$$
$$= g(Qp) . Qp - h(Qp).Qp - FC$$

$d\Pi/dQp = g'.Qp + g - h'.Qp - h = 0$, and by substituting Qp in the equation, the value of WY can be obtained, where Π = profit, Pp = price of pump water, Qp = quantity available for pumping, AC = average cost of pump water, and FC = fixed cost.

Inverse demand function: $Pp = \underset{(1.622)}{36.47} - \underset{(0.27)}{2.77\ Qp^{**}}$

Output function: $Qp = \underset{(.784)}{-0.237} + \underset{(.177)}{1.19\ WY^{**}}$

Cost function: $AC = \underset{(0.49)}{11.001^{*}} - \underset{(0.063)}{0.491\ Qp^{**}}$

**, * significant at 1% and 5% levels, respectively. Values in brackets are standard errors; the profit maximizing levels of WY and Qp are 5 meters and 5.59 hours, respectively.

Well owners maximize profits from water sales when the water level is about 5 meters and this corresponds to about 5.6 hours of pumping per day from the well. Under these conditions, output of well water can best be increased by having farmers install more wells and with increased competition. With more wells, the demand for water from each individual well will fall, resulting in a lower price for well water. According to a detailed survey, the number of wells can be increased in many tank command areas by 25% over the existing number (Palanisami and Flinn 1988).

Considering the following assumptions the number of wells that can be dug in the study area was assessed using the block-level data. Sample tanks with source of well-water supply for irrigation fall under three blocks in Sivagangai and Madurai districts. Block-level data from Thirupuvanam and Sivagangai blocks in the Sivagangai District were used to explore the possibilities of digging more wells in that particular block where tanks-with-wells are the major source of irrigation.

The assumptions for the above estimation of groundwater recharge are:

1. 10% of the annual rainfall in the total geographical area contributes to groundwater recharge.
2. 50% of the total command area was considered as the water-spread area (Palanisami and Easter 2000).
3. About 550 mm of water percolate from the total command area and the water-spread area.
4. About 30% of the recharge is considered as losses.

The number of wells that can be dug in these two blocks is given in Table 18.

Table 18. Groundwater recharge and additional wells.

Blocks	Thirupuvanam	Sivagangai
Total geographical area (ha)	32,073	44,660
Average annual rainfall (mm)	905	905
10% goes for recharge (ha. cm)	290,164	404,039
Total command area (ha)	13,600	4,562
Water-spread area (ha)	6,800	2,281
Total (ha)	20,400	6,843
Infiltration (ha.cm)	1,122,005	376,391
Total recharge (ha.cm)	1,412,170	780,430
Net recharge (ha.cm)	988,519	546,301
Current extraction (ha.cm)	640,093	304,166
Balance available (ha.cm)	348,426	242,135
Average annual pumping hours	1,116	1,016
Number of wells to be installed	312	238

Stabilization Value of Groundwater in Tank Irrigation Systems

Tanks serve the purposes of irrigation and enriching the water table through percolation. The function of tanks is extremely useful in maintaining the water table to ensure sustained growth of flora and fauna in the region. In recent years, due to poorly maintained structures (bunds, surplus weirs), siltation of tank beds and disintegrated channels and weirs most of the tanks are in a bad state (Palanisami and Easter 2000).

Supplies of tank water fluctuate randomly from year to year and within a year. Using 40 years' rainfall data, it was estimated that out of 10 years tanks will be experiencing deficient supply in 5 years; will fail in 3 years; and in will have full supply in 2 years (Palanisami et al. 1997). The poor performance of the tanks has resulted in heavy dependence on groundwater supplementation. Groundwater stocks, on the other hand, are relatively stable because the wells get recharged from both tanks and irrigated rice fields (Palanisami and Easter 2000).

Normally the number of supplemental irrigations required by the farmers could not be met as only about 15% of the farmers owned wells in the tanks (Palanisami and Flinn 1989). Most of the farmers in the tank irrigated areas are marginal farmers each having less than a hectare and it is expensive for them to invest in wells to meet the supplemental water requirements. It is argued that the government can invest in community wells or encourage the farmers to invest in their private wells so that all the farmers in the tank systems can share the tank and well water. This is possible only when the value attributed to the groundwater, i.e., stabilization value of groundwater, is attractive. The justification for increasing the number of wells in the tank systems is based on the stabilization value of groundwater supplementation.

Stabilization Value of Groundwater

The concept of "stabilization value of groundwater' was introduced by Tsur (1997). Unless the value of groundwater supplementation is attractive at the system level, subsequent investment in new wells by the farmers or the government agencies cannot be justified. Hence, it is important to study the value of groundwater at the tank level. As such, groundwater supplementation reduces the variability associated with tank water, since in most of the years tank storage is below normal. In the periods with below-normal tank supply, if groundwater is not supplemented the crop yield will be drastically reduced or the crop will fail completely. The variable reducing value of the groundwater carries an economic value, which is designated as the stabilization value of groundwater. The stabilization value is largely relative to the overall value of groundwater (Ranganathan and Palanisami 2004). Given the erratic tank-filling behavior over the years, groundwater supplementation is highly warranted. However, at the individual farm level, it is easy to appreciate the value of groundwater through additional increases in the rice yield, which also varies between farms and tanks depending on the level of groundwater supplementation.

Cross-sectional data related to the selected tanks with the source of irrigation of tank-with-wells in Sivagangai and Madurai districts of Tamil Nadu state were used to estimate the stabilization value of groundwater in the tanks. These tanks are located in a homogenous region, and inter-tank differences in terms of rainfall, storage pattern, filling pattern and irrigation pattern were observed to be the same.

In the tank-with-wells situation, farmers grow more than one crop. The choice of crop is also not restricted to paddy alone. Field-level data regarding the water usage relating to various crops were used to estimate the total water usage of each crop in the particular region. For each crop, various levels of water and corresponding yields were used in the analysis of the production function. The cost of surface water was calculated, based on the prevailing water charges fixed by the government for different crops in the region. With respect to the cost of groundwater, annualized cost of wells was arrived at using an 8% discount rate and 20 years' life of the well, and using the total hours of pumping, the unit cost of groundwater pumped was worked out. Finally, the total water use at the tank level was arrived at by summing up the water use by different crops. The water losses were also accounted in the computation. Normally, under the tank system, 38% of water is lost in seepage and percolation from both the canals and the fields (Government of Tamil Nadu 1996).

Estimation of Demand Curve for Water

A quadratic production function was employed to estimate the crop responses to water.

$Y_i = a + bX_i + cX_i^2$

where,

Y_i = Yield in kg per ha to crop i (i = 1 to 5) and

X_i = Water applied in cm per ha to crop i

Particulars of yield (Y) were gathered from the farmers. Quantity of water applied (X) was quantified using the formula Q = Discharge rate × hours of irrigation × number of irrigation for well irrigation; Q= Area of planting × depth of irrigation × number of irrigations The total quantity of water was calculated by adding the quantity of water from both tank and well irrigations using this value as X.

Using the results of the quadratic production function for various crops, the value of marginal products (VMP) was derived for each crop (Table 19). The VMP and water requirements of the different crops are presented in Table 20.

Table 19. Quadratic functions for different crops and the VMP.

Crop	Fitted quadratic function	Marginal product (kg)	P_y (Rs/kg)	VMP (Rs)
Paddy	$Y = 2227.58 - 48.49 X + .579 X^2$ ($R^2 = 73\%$)	42.75	7.44	318.00
Sugarcane	$Y = -141312 + 2092.7 X + 5.86 X^2$ ($R^2 = 94\%$)	444.00	1.00	444.00
Coconut	$Y = -5761.65 + 133.61X + .365 X^2$ ($R^2 = 85\%$)	187.79	2.86	537.00
Banana	$Y = 20788.49 - 529.65 X + 3.783 X^2$ ($R^2 = 93\%$)	258.50	7.22	1,866.37
Cotton	$Y = 1277.668 - 88.5 X + 2.75 X^2$ ($R^2 = 73\%$)	43.45	27.60	1,199.00

Table 20. Value of marginal product (VMP) and total water used for different crops.

Crops	VMP (Rs)	Total water used (ha.cm)
Banana	1,866	1,154
Cotton	1,199	2,382
Coconut	536	23,725
Sugarcane	444	93,092
Paddy	318	214,311

The amount of total water used was arrived at in a cumulative manner taking the mid-point values in the histogram. This value of marginal product of each crop and its total water requirement were plotted in the histogram. By arranging the crops in descending order of the value of marginal value of the irrigation water, an approximate value of marginal productivity curve for irrigation water was obtained. Then using these data, an exponential form of the demand curve for water was derived (Figure 1).

$$\pi(s) = \int_o^s Y dw - p_s s$$

$$= \int_o^s \mathrm{ae}^{-\mathrm{kw}} \mathrm{dw} - \mathrm{p_s s}$$

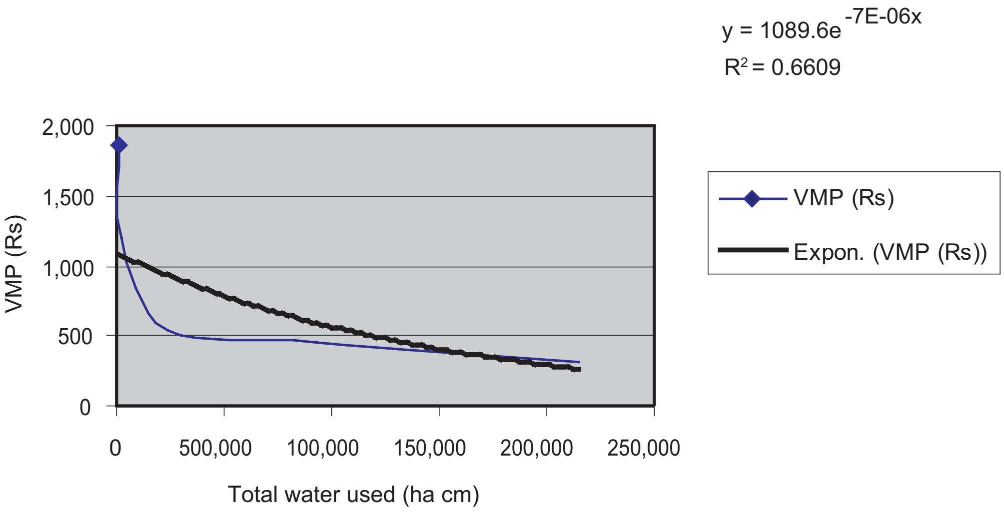
$$= \frac{a}{k}(1 - \mathrm{e}^{-\mathrm{ks}}) - \mathrm{p_s s}$$

Similarly,

$$\pi(s+g) = \frac{a}{k}\left(1 - e^{-k(s+g)}\right) - p_s s - p_g g$$

where, π = profit in Rs, s=surface water quantity in ha.cm, g=groundwater quantity in ha.cm, p_s=price of surface water in Rs/ha.cm, p_g=price of groundwater in Rs/ha.cm and a, k=coefficients estimated from the model.

Figure 1. Demand curve for water.



For each tank the values of groundwater and surface water were calculated as follows. Let S_t t = 1,2 3,……..12 denote the surface water realization for 12 tanks. Let g_t be the groundwater demand in each tank associated with S_t and $\Pi\ (S_t+g_t)$ be the corresponding profit. The value of the groundwater when surface water supply was S_t equals $\Pi\ (S_t+g_t) - \Pi\ S_t$. The average was calculated by the following formula (Tsur 1997).

$$(1/12)\sum_{i=1}^{i=12} [\ \Pi\ (S_t+ g_t) - \Pi\ (S_t)]$$

The profit with groundwater minus the profit without groundwater gives the value of groundwater had surface water been stable at the mean level. The difference between the groundwater value and the groundwater value at mean level gives the stabilization value. The results are presented in Table 21.

Table 21. Profit and stabilization value of groundwater.

Tanks	Surface water (S) (ha.cm)	Groundwater (G) (ha.cm)	Profit (S) (Rs)	Profit (S+G) (Rs)	Profit ([S+G[-S) (Rs)
1	24,315	10,922	24,312,839	32,884,588	8,571,748
2	14,497	11,626	14,991,739	24,821,396	9,829,656
3	12,828	3,582	13,342,897	16,508,258	3,165,361
4	7,131	7,401	7,565,185	14,301,039	6,735,854
5	8,018	9,812	8,480,203	17,267,300	8,787,096
6	14,974	10,922	15,459,675	24,684,432	9,224,756
7	4,342	4,039	4,651,560	8,456,842	3,805,282
8	1,440	774	1,557,875	2,313,442	755,567
9	799	981	866,743	1,828,132	961,389
10	1,562	836	1,689,571	2,504,242	814,672
11	1,488	1,334	1,609,667	2,907,942	1,298,275
12	1,406	386	1,521,824	1,899,369	377,546
Average	7,733	5,218	8,004,148	12,531,415	4,527,267
Profit at average S	7,733	5,218	8,186,828	12,531,415	4,344,586.762
Stabilization value of groundwater (Rs)					82,680.3
Proportion of stabilization value to total value of groundwater (%)					4.04

The average value of the groundwater equals Rs 4,527,267. The profit, assuming that the surface water supply was stable at the mean level (7,733 ha.cm), equals Rs 4,344,587. The difference between these two rows is Rs 182,680 which is the stabilization value of groundwater. This was the value of groundwater due to its role in stabilizing the supply of irrigation water (disregarding its role in increasing average supply of irrigation water). The stabilization value of groundwater accounted for 4% of the total value of groundwater assuming that surface water supplies were stable at the mean level and would bias assessments of groundwater benefits downward by 4%.

Production Efficiency of the Farmers in Different Typologies

Normally, when endowed with adequate resources, farmers use inputs in excess, expecting to reap higher yields. The excessive cost thereby included in the production process could not only bring down their profit but waste the scarce resources. Subsidized agricultural inputs could stimulate extensive use of other inputs. For instance, if irrigation water is available in plenty and at subsidized rates, where water charges are minimal, farmers are tempted to use the other resources like fertilizer, labor, etc., indiscriminately to get higher yields. However, not all the farmers are irrational in their input use. Hence, it is necessary to study the efficiency of the crops produced by the farmers, which will help address the issues of yield gap, etc.

Technical, Allocative and Economic Efficiencies of Farmers

Production efficiency has two components: technical and allocative. Technical efficiency (TE) is the extent to which the maximum possible output is achieved from a given combination of inputs. On the other hand, a producer is said to be allocatively efficient (AE) if production occurs in a subset of the economic region of the production possibilities that satisfy the producer's behavioral objective.

Technical efficiency is the ability to produce a given level of output with a minimum quantity of inputs under a certain technology. Allocative efficiency refers to the ability of choosing optimal input levels for given factor prices. Overall productive efficiency or economic efficiency (EE) is the product of technical and allocative efficiency. Thus, if a farm has achieved both technically efficient and allcatively efficient levels of production, then it is economically efficient and new investment streams may be critical for any new development

Average, minimum and maximum technical, allocative and economic efficiencies of the farms in the study area are presented in Table 22. As there is no single crop cultivated in all three typological situations, the farmers cultivating paddy in the tank-only and the tank-with-wells situations and the farmers cultivating sugarcane in the tank-with-wells and the wells-only situations were used for estimation purpose. The TE of all four groups of farmers such as farmers cultivating paddy in the tank-only situation and the tank-with-wells situation and farmers cultivating sugarcane in the tank-with-wells and the wells-only situations is higher than the AE and EE. The paddy farmers in the tank-with-wells situation are technically more efficient than the paddy farmers in the tank-only situation. Likewise, sugarcane farmers, in the wells-only situation are technically more efficient than those in the tank-with-wells situation.

The results indicate that the TE indices range from 40 to 95% for the paddy farms in the tank-only situation with an average of 82% (Table 22). This means that if the average farmer in the sample is to achieve the TE level of his most efficient counterpart, then the average farmer could realize 14% cost savings (i.e., 1-[82/95]). A similar calculation for the most technically inefficient farmers reveals cost savings of 58% (i.e., 1-[40/95]). The mean AE of the sample is 61%, with a low of 45% and a high of 83%. The combined effect of technical and allocative factors shows that the average EE level for this sample is 51% with a low of 21% and a high of 73%. These values indicate that if the average farmer in the sample is to reach the EE level of his most efficient counterpart, then the average farmer could experience a cost saving of 30% (i.e., 1-[51/73]). The same computation for the most economically inefficient farmer suggests a gain in EE of 71% (i.e., 1-[21/73]).

Table 22. Mean, minimum and maximum technical, allocative and economic efficiencies of paddy and sugarcane farms in different typologies.

	Paddy		Sugarcane	
	Tank-only	Tank-with-wells	Tank-with-wells	Wells-only
TE				
Mean	82	85	92	93
Minimum	40	59	72	85
Maximum	95	97	98	96
AE				
Mean	61	74	76	50
Minimum	45	66	56	32
Maximum	83	89	81	96
EE				
Mean	51	63	70	47
Minimum	21	45	52	29
Maximum	73	82	77	92

In the tank-with-wells situation, the EE ranges from 59% to 97% with the average of 85% for paddy farms. This means that if the average farmer in the sample is to achieve the TE level of its most efficient counterpart, then the average farmer could realize 12% cost savings (i.e., 1-[85/97]) and the same computation for the most technically inefficient farmer reveals cost savings of 39% (i.e., 1-[59/97]). The mean AE of the sample is 74%, with a low of 66% and a high of 89%. The mean EE is 63% with a low of 45% and a high of 82%. If the average farmer in the sample is to reach the EE level of its most efficient counterpart, then the average farmer could experience cost savings of 23% (i.e., 1-[63/82]) and the same computation for the most economically inefficient farmer suggests a gain of 45% (i.e., 1-[45/82]).

In sugarcane farms under the tank-with-wells situation the TE ranges from 72 to 98% with the average of 92%. This means that if the average farmer in the sample is to achieve the TE level of his most efficient counterpart, then the average farmer could realize 6% cost savings (i.e., 1-[92/98]) and the same computation for the most technically inefficient farmer reveals cost savings of 27% (i.e., 1-[72/98]). The mean allocative efficiency of the sample is 76%, with a low of 56% and a high of 81%. The mean EE is 70% with a low of 52% and a high of 77%. If the average farmer in the sample is to reach the EE level of his most efficient counterpart, then the average farmer could experience cost savings of 9% (i.e., 1-[70/77]) and the same computation for the most economically inefficient farmer suggests a gain of 32% (i.e., 1-[52/77]).

In sugarcane farms under the wells-only situation the TE ranges from 85% to 96% with the average of 93%. If the average farmer in the sample is to achieve the TE level of his most efficient counterpart, then the average farmer can realize 3% cost savings (i.e. 1- [93/96]) and the same computation for the most technically inefficient farmer reveals cost savings of 11% (i.e., 1-[85/96]). The mean AE of the sample is 50%, with a low of 32% and a high of 96%. The mean EE is 47% with a low of 29% and a high of 92%. If the average farmer in the sample is to reach the EE level of his most efficient counterpart, then the average farmer can experience cost savings of 49% (i.e., 1-[47/92]) and the same computation for the most economically inefficient farmer suggests a gain of 68% (i.e., 1-[29/92]).

The mean AE of farms in the wells-only situation is low compared to the tank-with-wells situation. Though the water supply is assured, the cost of inputs is very high when compared to other situations. The average wage rate of labor in the wells-only situation is Rs 175/day and the same costs Rs 85/day in the tank-with-wells situation. This affects the allocative efficiency in the wells-only situation. As the EE is the combined effect of TE and AE, the mean EE of the wells-only situation is only 47%.

Tank Management and Modernization

The critical factor in conjunctive water use will be managing the release of tank water over the season depending on rainfall and groundwater supplies. Ideally, a water user association (WUA) working with a technical advisory group from the State Government would decide on a strategy for water releases for the crop season. In some years, it may mean a continuous flow because of abundant supplies while in others it may mean keeping the sluices closed throughout the season and using the tank in the tank-only situation to recharge the groundwater.

The best way to induce changes in collective tank management may be to combine management changes with modernization activities. Such activities could include sluice modification or repair, additional wells, limited canal lining, partial tank desilting, improved maintenance or catchment management, such as providing feeder channels or contour bunds. These physical improvements alone, or in combination with management improvements, such as sluice management or the rotation of deliveries, generated substantial returns, although the B/C ratios were less than 2.0 (Table 23).

Table 23. Benefit/Cost (B/C) ratios and internal rates of return (IRR) for different tank improvement strategies, Tamil Nadu.

	Project life (years)	B/C ratio	IRR (%)
Additional wells	10	1.4	26
Canal lining + additional wells	8	1.2	21
Sluice management + additional wells + canal lining	15	1.4	25

Although, on average, tanks have lost 20% of their capacity due to accumulation of silt, removal of silt is expensive unless farmers want the silt for use on their farms.[2] The cost of partial desilting, including excavation and transport, is about Rs 15/m^3 (Table 24). Such expenditures may offer economic returns if the silt is removed in key places such as those adjacent to the sluices.

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[2] Quantity of the silt is the difference between original and actual tank storage capacities using the formula C = a1+a2+(a1*a2)1/2H, where C=total storage capacity in cu.m; a1, a2=areas under contours (in m^2); H=difference between contours in m.

Table 24. Cost of partial desilting of tanks.

Type	%	Cost (Rs/m^3)
Excavation		
Manual	25	30.50
Mechanical excavator	75	17.00
Transport[1]		
Manual	5	25.00
Mechanical excavator	95	19.00

[1] Only about 15% of the silt removed needs transport around the tank water-spread area.

Strategies involving maintenance of newly rehabilitated structures may be needed. Without maintenance, these tanks will deteriorate rapidly and the rehabilitation investments will be lost. A separate maintenance provision could be included in the budget for the rehabilitated structures. Another, even better, alternative would be to require that farmer associations agree to take over the responsibility for maintenance before the structures are rehabilitated. Alternatively, the government could establish a separate budget allotment for maintenance of rehabilitated structures, which would be funded by increased water charges on the rehabilitated tanks.

However, improved water management may also require institutional changes before they become fully effective. In many cases, farmer associations will need to be formed and take over the responsibility for O&M of the tanks (government turnover of tanks to farmers). The government could establish a tank management authority to provide farmers with technical assistance for improving their tank management. It is also possible to transfer PWD tanks to the panchayat unions if the latter tanks perform better in terms of resource mobilization, water distribution, and overall tank management. Since each tank has its own management issues, the appropriate management strategies should be identified after studying each existing tank.

Selecting the Appropriate Management Strategy

It is important to identify tank management strategies in association with groundwater supplementation. In deciding on the rules for managing sluice gate operations it will be important to involve all groups served by the tank. Not all water users will be affected in the same way. In fact, some may lose while others benefit. The primary groups likely to be affected by tank management changes include: well owners, non-well owners, encroachers (legal and illegal), watermen, fisherman and local panchayats (Table 25).

Table 25. Distribution of possible benefits from tank management changes.

Actors	Level of benefits
Well owners	High
Non-well owners	Medium
Legal-encroachers	None (loss)
Illegal-encroachers	None (loss)
Watermen	Low
Fishermen	Medium
Panchayat	Medium
WUAS	High

The largest beneficiary may be the well owner in the command. Since only comparatively well-off farmers could invest in wells, the management changes may tend to benefit higher-income farmers the most. However, these well owners normally sell the well water to other farmers during the later part of the rice crop season. It is highly likely that these well owners will continue to sell well water to the non-well owners. Since electricity is free to farmers, the well owners will be encouraged to sell the water at a comparatively low price. To make sure that the management change works, it is important to have a detailed dialogue between the well owners and the non-well owners. The local panchayat or WUA could play a role in arriving at an agreeable solution. The WUA will benefit from the changes and dialogue, since there would be fewer conflicts to be resolved to improve water distribution.

There are both legal and illegal encroachers in the tank beds or foreshore areas. The legal encroachers are those who have obtained legal rights to cultivate these foreshore lands when these areas are not submerging. However, there are illegal encroachers, who cultivate the foreshore areas by paying a penalty. Since tanks will likely have standing water for a longer period under the new management strategy, the encroachers may not be able to cultivate in most years. The local panchayat and WUA will need to prevent the encroachers from illegally opening the sluice gates to lower the water level in the tank. Watermen and fishermen in the tanks have comparatively minor roles in most tanks and the new management strategy may not affect them much. Fishermen who have fishing rights may benefit since the tanks will have storage for a longer time. In the case of watermen, they could be given the responsibility to carry out the new management rules.

However, there are also cost considerations. There will be additional electricity consumption due to extra pumping by the well owners, because they will need to pump for the neighboring non-well owners. Since electricity is free to farmers, it will add an extra burden to the state electricity boards. Currently, the Village Administrative Officer (VAO) at the village level is collecting the water charges, cess, and surcharges from the tank-beneficiary farmers. The tank water charges go to the Revenue Department and the cess and surcharges are used by the panchayat for village improvements.

The most domestic management change would be to close the sluices permanently and use the tank as a percolation pond. In several locations, where well intensity is quite high and over 50% of the tank storage capacity has been lost, this might be a good strategy. In fact, this was effected in several cases in Andhra Pradesh.

Conclusions and Recommendations

Due to increasing scarcity of tank water, the demand for supplemental irrigations is increasing. However, the majority of farmers are not operating at the economic optimum level of well water use. This is due to the inadequate number of wells in the command area, as well as the limited water availability in existing wells, particularly during December and January. In many locations, groundwater levels declined by about 1-2 meters in the 1970s and by an additional 2-4 meters in the 1980s. Under constraints of poor recharge from rains, wells depend heavily on tank water supplies for recharge.

Well owners maximize profits from water sales when the water level in the well is about 4 meters. Under these conditions, output of well water can best be increased by having farmers install more wells and increase the competition where well density is less than one well per 10 ha, With more wells, the demand for water from each individual well will fall, resulting in a lower price in well water. Still priority should be given to both the tank and well management for efficient conjunctive use of tank and well water.

This can be achieved by a series of actions that will increase the availability of tank and well water. First, physical and management measures can be taken to improve the runoff from catchment areas. Second, physical and management activities can be used to improve the effective supply of water delivered from the tank. Third, in areas with less than one well per 10 ha, government incentives can be used to promote the development of wells. Fourth, WUAs should be supported and encouraged to coordinate the use of tank and well water supplies. Last, where tanks have lost more than 50% of their storage capacity, and there is a high concentration of wells, it may be best to use the tanks as percolation tanks.

Recommended Strategies for Sustaining Tank Irrigation

1. Since groundwater supplementation is an integral part of the tank system, it is important to maintain the number of wells at the threshold level (i.e, one well per 2 ha in the wells-only situation, one well per 4 ha in the tank-with-wells situation and one well per 10 ha in the tank-only situation). This means the WUA should be encouraged to maintain tank management in such a way that the digging of additional wells above the threshold level is discouraged.
2. In situations where tanks cannot have adequate supply for crop cultivation, it is possible to convert them into percolations tanks, as the productivity and income are comparatively higher even after inclusion of the additional pumping costs due to such tank conversions. Hence, government can initiate a detailed survey on the tanks and can encourage the tank conversion into percolation tanks. This will thus help maximize crop production and income at both the tank and the farm level.
3. Since only about 15% of the farmers own wells in the command area, supplemental irrigation at the end of the crop season can be done through water markets. Hence, water markets should be encouraged at the tank level through coordination of well owners using both tank management and well recharge strategies. Efforts should be taken in such a way that all the tanks could provide at least two supplemental irrigations to the paddy crop. The tank and groundwater management should be conjunctively used to provide the required number of supplemental irrigation.

4. The optimum number of pumping as evidenced from the study should be maintained in all tanks which will have a positive impact on the water market and pricing of well water when overexploitation of groundwater will be minimized.
5. Given the budget constraints, tank rehabilitation or modernization should start with management options followed by physical investments as indicated by the higher internal rate of returns. The national and international agencies should give priority for tank rehabilitation and management based on the groundwater supplementation aspects.
6. Crop diversification towards non-rice crops such as pulses and oilseeds should be encouraged, as the tanks have less than 50% storage in most of the years which is insufficient for rice cultivation. Needed agricultural extension efforts with marketing facilities should be promoted at the tank level.

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Impact of Watershed Development Programs in Tamil Nadu

K. Palanisami and D. Suresh Kumar

Introduction

The concept of integrated and participatory watershed management has emerged as the cornerstone of rural development in the dry, semiarid and rain-fed regions of the world. Most watershed projects in India are implemented with the twin objectives of soil and water conservation and enhancing the livelihoods of the rural poor (Sharma and Scott 2005). A watershed is a geographical area that drains to a common point, which makes it an attractive unit for technical efforts to conserve soil and maximize the utilization of surface water and subsurface water for crop production (Kerr et al. 2000). Watershed development has been conceived basically as a strategy for protecting the livelihoods of the people inhabiting the fragile ecosystems experiencing soil erosion and moisture stress.

Different types of treatment activities are carried out in a watershed. They include soil and moisture conservation measures in agricultural lands (contour/field bunding and summer ploughing), drainage line treatment measures (loose boulder check dam, minor check dam, major check dam, and retaining walls), water resources development management (percolation pond, farm pond, and drip and sprinkler irrigation), crop demonstration, horticulture plantation and afforestation (Palanisami and Suresh Kumar 2005). Periodically, training in watershed technologies and related skills is also given to farmers in watersheds. In addition, members are also taken to other successful watershed models and research institutes for exposure. These efforts appear to be contributing to groundwater recharge. The aim has been to ensure the availability of drinking water, fuelwood and fodder and raise income of, and employment opportunities for, farmers and landless laborers through improvement in agricultural production and productivity (Rao 2000). Today, watershed development has become the main intervention for natural resource management. Watershed development programs not only protect and conserve the environment but also contribute to livelihood security.

As an important development program, watershed development received much attention from both the central and state governments. Up to the Tenth Plan (till March 2005), 17.24 million hectares (Mha) were treated with a total budget of Rs 93.6803 billion under the Ministry of Agriculture, 27.52 Mha with an outlay of Rs 68.5566 billion under the Ministry of Rural Development and 0.82 Mha with an outlay of Rs 8.1373 billion under the Ministry of Environment and Forest. Altogether, 45.58 Mha were treated through various programs with an investment of Rs 170.37 billion. Average expenditure per annum during the Tenth Plan was around Rs 23 billion (Department of Land Resources 2006). As millions of rupees were spent on watershed development programs it is essential that the programs become successful.

With the programs so large and varied, it is important to understand how well they function overall and which aspects should be promoted and which dropped. Keeping these issues in view, the present paper examines the overall performance of watershed development programs in Tamil Nadu.

Watershed Development Programs - An Overview

Watershed development has emerged as a new paradigm for planning, development and management of land, water and biomass resources following a participatory bottom-up approach. Some important ongoing watershed development programs include Drought Prone Area Programme (DPAP), Desert Development Programme (DDP), River Valley Project (RVP), International programs of DANIDA, DFID (UK), SIDA, and state-funded watershed development programs, etc. In addition, based on experience, the Government of India recently created the Watershed Development Fund (WDF) in collaboration with NABARD. The objective of the fund is to create the necessary conditions to replicate and consolidate the isolated successful initiatives under different programs in the government, semi-government and NGO sectors. In addition, several initiatives of people's participation in resource management also took place. Prominent among them are the Chipko Movement, Save Narmada Movement, AVARD's Irrigation Scheme, Water Council (Pani Panchayat), Ralegan Siddhi, etc. The Ralegan Siddhi is one among the very successful models of people's participation.

Most watershed projects are implemented within a well-defined institutional framework. A state-level committee called the State Watershed Development Committee coordinates different departments and evaluates progress. The District Watershed Development Committee undertakes similar tasks at the district level. It advises the District Rural Development Agency in selecting a Project Implementation Agency and members of a Watershed Development Team (WDT). The Project Implementing Agency (PIA) is responsible for implementing watershed activities and supervises the various tasks undertaken by community-based organizations.[1] The Watershed Development Team is made up of multidisciplinary members who provide technical guidance to the PIA and to community organizations.

The community-based organizations (CBOs) involved in managing watersheds are the Watershed Association (WA), the Watershed Committee, User Groups, and Self-Help Groups. The WA is made up of members who are directly or indirectly dependent on the watershed area.[2] The President of the WA is the Chairman of the Watershed Committee, which carries out the day-to-day activities of watershed management.[3] Self-Help Groups are homogeneous groups whose members share a common identity such as agricultural laborers, landless households, women, shepherds and scheduled castes/tribes. These groups focus on micro-finance thrift groups, small shops, goat-rearing, etc.

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[1] The PIA prepares development plans, undertakes community organization training, provides technical guidance, monitors and reviews implementation and sets up institutional arrangements for post-project operation.

[2] The WA is expected to be formally registered as a society.

[3] These activities include planning, resolving disputes, identifying procedures for the O&M of assets, and facilitating the creation of the Watershed Development Fund, ensuring accuracy of accounts and so on.

Generally, watersheds in India are allotted a budget of approximately Rs 6,000 per ha. Thus, a watershed with a total area of 500 ha receives Rs 3 million for a 5-year period. The bulk of this money (80%) is meant for development/treatment and construction activities.[4] The WC opens a bank account and directly uses these funds. To promote participation of local villagers in the implementation of watershed programs, guidelines for watershed development were first issued in 1995 and subsequently revised in 2001. These guidelines emphasized the formation of CBOs.

But, by and large, these community-based watershed management initiatives have not produced the desired results in terms of people's participation, particularly once the state withdraws its support (Rao 2000; Palanisami and Suresh Kumar 2002). This led to further revision of guidelines and the involvement of the *panchayat raj* (local government) institutions in the planning, implementation and management of watersheds. New guidelines called the Haryali guidelines were issued in April 2003. Under the new Haryali guidelines, the village panchayats take the role of the Watershed Committee and the higher-level Gram Sabha represents the WA. Realizing the lacuna of different guidelines, in 2008, the Government of India issued new guidelines called Common Guidelines for Watershed Development Projects.

Watershed Development in Tamil Nadu

Profile of the State

Agriculture is the major occupation in the state as it provides livelihood support to 56% of the population. Incidentally, about 56% of the total cropped area of the state is under irrigated condition while around 44% of the area is under dryland farming. Land use pattern in the state has witnessed significant changes over the years. The net sown area has declined from 48% of the total geographical area during 1979-80 to 42.8% in 1999-2000 and further to 38.5% in 2005-06. Tamil Nadu agriculture is dominated by marginal and small farmers. The marginal farmers account for 74.3% of the total holdings operated only in about 30% of the total area while the semi-medium, medium and large farmers account for a small proportion of 10% of the holdings operated in a higher proportion of 46.1% of the total area. The number of marginal farmers has been increasing over the years.

Tamil Nadu (Figure 1) state which accounts for 7% of the population of the country is endowed with only 3% of water resources in India. The water potential of the state is 46,540 Mm^3. The groundwater potential available for future development was estimated at 3,142.27 Mm^3 as of January 2003.

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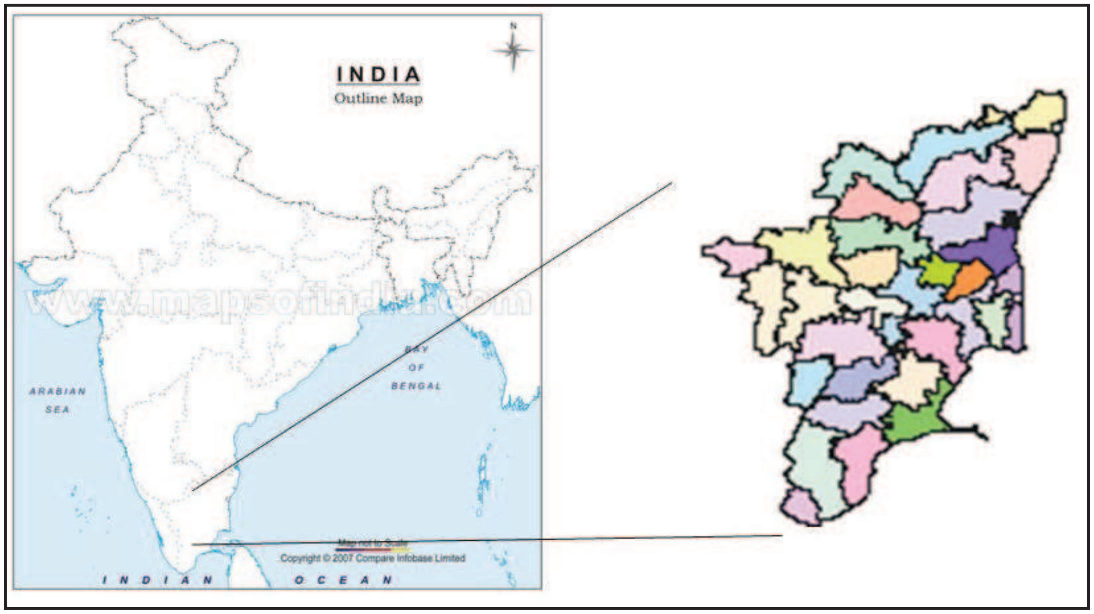
[4] Funds are allotted for different activities as follows: Watershed treatment/development works -- 80%; CBOs including entry point activities -- 5%; training -- 5%; administrative overheads --10%. According to the new common guidelines of 2008, the budget allotment is Rs 12,000 per ha.

Figure 1. Map of the State of Tamil Nadu.



Also the development of groundwater has led to increased "drought proofing" of the state's agricultural economy. An analysis of the variance in growth rates of irrigated and unirrigated agriculture after the advent of new technology in the late 1960s revealed that the degree of instability in irrigated agriculture was less than half of that in unirrigated agriculture (World Bank 1998). Out of 385 blocks in Tamil Nadu, 180 blocks have almost exploited the potential and out of the 1.8 million wells in the state, about 12% are dried up or abandoned due to groundwater overexploitation (GoTN 2002). In some pockets of the state, the average well failure rate is 47% for open wells and 9% for bore wells (Palanisami et al. 2008). Being a hard-rock region, the externalities of groundwater depletion are felt in most parts of the state. The overexploitation of groundwater in many areas of the state has resulted in lowering of the water table below the economic pumping level. In this context, the watershed development assumes critical proportions in the state.

Watershed Development Programs

To increase the overall agricultural production and improve the living conditions of the farmers depending on the rain-fed lands, the watershed development programs are being widely implemented in the state. There are 19,331 micro-watersheds identified in the state of which, approximately 4,000 have already been treated. The details of number of watersheds in the state are given in the Annex. The important programs such as DPAP, National Watershed Development Project for Rain-fed Areas (NWDPRA) and Integrated Wasteland Development Programme (IWDP) are implemented through a watershed approach apart from the Comprehensive Watershed Development Projects implemented with assistance from DANIDA.

The DPAP is implemented with the prime objective of promoting the overall economic development of the watershed community through optimum utilization of natural resources, employment generation and restoring ecological balance. The program is implemented in 80 blocks of 16 districts which are Dharmapuri, Thoothukudi, Sivagangai, Ramanathapuram, Virudhunagar, Pudukottai, Tirunelveli, Salem, Namakkal, Coimbatore, Tiruvannamalai, Dindigul, Vellore, Tiruchirappalli, Perambalur and Karur. From 1999-2000 to 2006-07, the Government of India sanctioned 1,222 watersheds in seven batches at a total cost of Rs 3,367 million, for treating a total area of 0.61 Mha (GoTN2009).

The IWDP has been under implementation in Tamil Nadu since 1993-94 to develop non-forest wastelands on the principles of watershed development. This program is being implemented in 96 blocks of 24 districts, which are Coimbatore, Dharmapuri, Dindigul, Karur, Krishnagiri, Namakkal, Perambalur, Pudukkottai, Ramanathapuram, Salem, Sivagangai, Tiruvannamalai, Thoothukudi, Tiruchirappalli, Tirunelveli, Vellore, Erode, Theni, Madurai, Kancheepuram, Villupuram, Tiruvallur, Cuddalore and Virudhunagar. From 1999-2000 to 2006-07 the Government of India has sanctioned 910 watersheds at a total cost of Rs 2,622. 039 million, for treating a total area of 0.457 Mha (GoTN 2009).

The other important watershed development program is the NWDPRA. It is being implemented in the state from 1990-91. During the period from 2002-03 to 2007-08, a altogether 755 watersheds (0.290 Mha) with a total outlay of Rs 1,306.5 million have been treated.

In addition to these major watershed development programs, watershed programs assisted by the National Bank for Agriculture and Rural Development (NABARD) are being implemented. This covers 100 watersheds at a cost of Rs 600 million in 23 districts of the state.

Impacts

The watershed development programs involving the entire community and natural resources influence (i) productivity and production of crops, changes in land use and cropping pattern, adoption of modern technologies, increase in milk production, etc., (ii) attitude of the community towards project activities and their participation in different stages of the project, (iii) socioeconomic conditions of the people such as income, employment, assets, health, education and energy use, (iv) impact on environment, (v) use of land, water, human and livestock resources, (vi) development of institutions for implementation of watershed development activities, and (vii) ensuring sustainability of improvements. It is thus clear that watershed development is a key to sustainable production of food, fodder, fuelwood and meaningfully addressing the social, economical and cultural conditions of the rural community.

Recognizing the importance of watershed development program in the state, a large number of studies attempted to assess the impact of watershed development over a period of time. These studies vary in purpose, regions and domain of impacts. The impact studies vary from impact of specific water harvesting interventions such as percolation ponds to overall impacts of the watershed development program. The impact assessment studies focus mainly on the impact of different interventions, such as water resources development, soil and moisture conservation measures, drainage line treatments and afforestation, and assess the impacts on different aspects like increase in surface water and groundwater resources, cropping pattern changes, yield, environmental conditions, and socioeconomic conditions including the social capital and institution building as a result of watershed interventions.

Biophysical impacts. The watershed development activities have significant positive impacts on various biophysical aspects, such as investment on soil and water conservation measures, soil fertility status, soil and water erosion, expansion in cropped area, changes in cropping pattern, cropping intensity and production and productivity of crops.

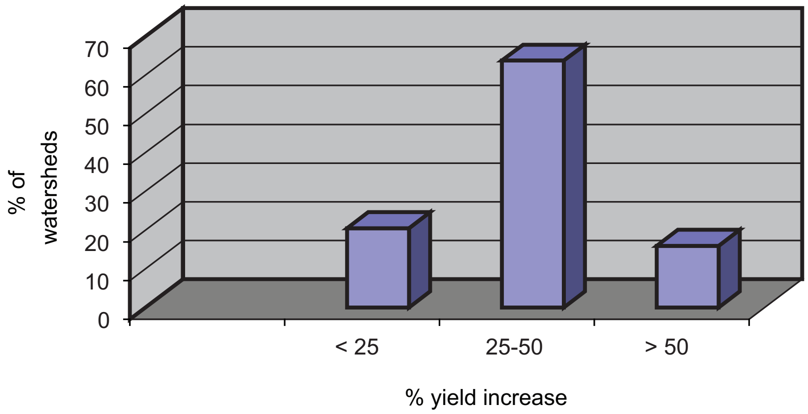
It is evident that the watershed treatment activities improved conservation of soil and moisture, improvement and maintenance of fertility status of the soil (Sikka et al. 2000; Ramaswamy and Palanisami 2002; Palanisami and Suresh Kumar 2002) and reduced soil and water erosion. The organic carbon increased by 37% due to watershed intervention (Sikka et al. 2000) and most studies revealed that there was a significant reduction in soil and water erosion.

An impact and evaluation study of the soil conservation scheme under DPAP indicates that only marginal impacts were realized in terms of land use pattern, crop pattern, yield rate, etc. (Evaluation and Applied Research Department 1981). Evidence shows that soil conservation appears to have had a positive impact on retention of moisture, reduced soil erosion, and change in land use pattern and yield. Soil loss reduced from 18,758 kg/ha to 6,764 kg/ha from 1988 to 1989. Between 1985-86 and 1989-90 the yield rate of all the crops had increased an annual compound growth rate (CGR) of 3.94% to 16.40% (Evaluation and Applied Research Department 1991).

Improvement in soil fertility coupled with increased water resources in the watershed area led to expansion in cropped area and cropping intensity, and increase in production and productivity of crops (Figure 2).

The cropping pattern changes have taken place both in additional area brought under well irrigation from the fallow lands and in the area under rain-fed cultivation. The area under high water-consuming crops increased by 25.3% in the first crop and by 29.4% in the second crop period (Evaluation and Applied Research Department 1991). Similarly, the evidence shows that the cropping intensity is increased from 120 to 146.88% in the Kattampatti watershed and 102.14 to 112.08% in the Kodangipalayam watershed (Palanisami and Suresh Kumar 2005). Increases in Crop Productivity Index, Fertilizer Application Index, and Crop Diversification Index were also observed (Sikka et al. 2000, 2001).

Figure 2. Percentage of watershed by increase in yield.



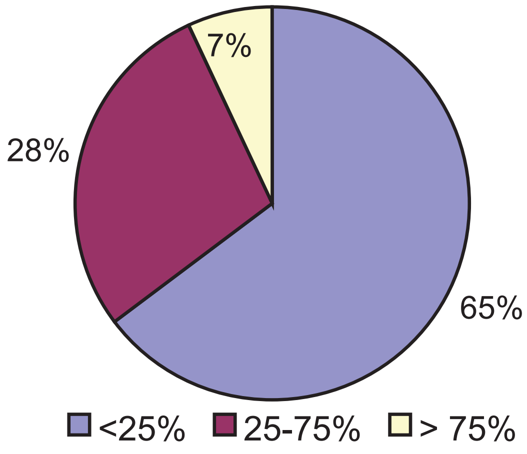
Environmental impacts. The watershed development activities generate significant positive externalities which have a bearing on improving agricultural production, productivity, and socioeconomic status of the people who directly or indirectly depend on the watershed for their livelihoods. The environmental indicators include water level in the wells, changes in irrigated area, duration of water availability, water table of wells, surface water storage capacity, differences in number of wells, number of wells recharged/defunct, differences in irrigation intensity and Watershed Eco Index (WEI).

The impact assessment studies conducted by different agencies and scientists across regions over a period of time imply that watershed development activities have generated significant positive impacts on the environment. One important objective of watershed development is in situ water and soil conservation and water resources development in the watershed village where the treatment activities helped in conservation and enhancement of water resources. Most of the studies report that water level in the wells increased leading to expansion in irrigated area in the watershed. Though many studies have not measured the actual increase in the water level in the wells, a few studies have made an attempt to do so. The increase in water level in the wells varied from 0.1 meter to 3.5 meters and this varied across seasons. Similarly, the expansion in irrigated area due to watershed development activities varied from 5.6 to 68% across regions and seasons. Experience shows that the increase in water level in the wells is observed to be less than 2 meters (57.22% of watersheds). About 30.48% of watersheds witnessed an increase of 2-5 meters and only 12.3% witnessed an increase of more than 5 meters in the water level in the wells.

The rainwater harvesting structures constructed in the watershed help enhance the surface water storage capacity. Structures like minor and major check dams, percolation and farm ponds, and renovation of irrigation tanks help in a big way to enhance the surface water storage capacity. Evidence shows that, on average, about 92 ha.cm additional capacity were created and varying from 63 ha.cm to 136 ha.cm. In addition to the fixed capacity, repeated storage will be available for different fillings once already stored water is percolated. A maximum additional storage capacity of 359 ha.cm was created in the Tiruppur block of the Coimbatore District of Tamil Nadu. The additional surface water storage created helped improve groundwater recharge and water availability for cattle and other nondomestic uses in the watershed villages. The duration of water availability in a year in the wells inspected during the sample survey was found to have improved as a result of watershed projects. The analysis of recuperation rate before and after watersheds indicates that the recharge rate had increased by 16 to 39%. It was also observed that recharge of wells decreased with their distance away from the percolation ponds and this influence could be generally observed up to a distance of about 500-600 meters (Palanisami and Suresh Kumar 2006; Sikka et al. 2000).

Impact of percolation ponds revealed an increase in water columns of wells from 1.2 to 1.8 meters. The gross irrigated area (GIA) increased by 13.6% by the pond intervention. Increase in GIA per well is 0.27 ha. The number of new wells in the zone of influence was 1-4 (Evaluation and Applied Research Department 1991). Palanisami et al. (2002) in their study in the Coimbatore District of Tamil Nadu used a combination of a with and without approach and a before and after approach to assess the impact of watershed development activities. It is evidenced that the additional surface water storage capacity created worked out to 9,299 m^3 in the Kattampatti watershed, comprising 4,245 m^3 from renovation of tanks, 4924 m^3 from percolation ponds, and 130 m^3 from construction of major and minor check dams. In the Kodangipalayam watershed, the additional water storage capacity created worked out to

Figure 3. Distribution of watershed by impact on irrigated area.



12,943 m^3. This additional storage capacity further helped improve groundwater recharge and water availability for livestock and other nondomestic uses in the village as a result of watershed treatment activities. The water level in the open dug wells has risen to 2.5 to 3.5 meters in Kattampatti and 2.0 to 3.0 meters in Kodangipalayam watersheds. The groundwater recuperation in the nearby wells was increased. The area irrigated increased and thus the irrigation intensity increased from 115.74 to 122.73% in the Kattampatti watershed and from 101.45 to 102.01% in the Kodangipalayam watershed.

Watershed development activities produced a significant positive impact on the water table, duration of water availability in the wells and pumping hours that resulted in an increased irrigated area and crop diversification (Sikka et al. 2000, 2001). Madhu et al. (2004) found that the conservation and water harvesting measures in the watershed helped improve the groundwater recharge, water availability for cattle and other domestic uses, increased duration of water availability in the streams, rise in water table in the wells, sediment trapping behind the conservation measures/structures and stabilization of the gully bed. The productivity of crops increased from 6.65 to 16.59% in the watershed village.

Planting trees in private farmlands and common lands is also being undertaken as part of the watershed development. This created additional green cover thus improving the environment. The Watershed Eco-Index which reflects the additional green cover created varied from 1.8 to 43% (Sikka et al. 2000, 2001; Palanisami and Suresh Kumar 2002; Ramaswamy and Palanisami 2002).

Thus it is lucid from the analysis that watershed development activities generate sufficient positive externalities and have significant impacts on the environment.

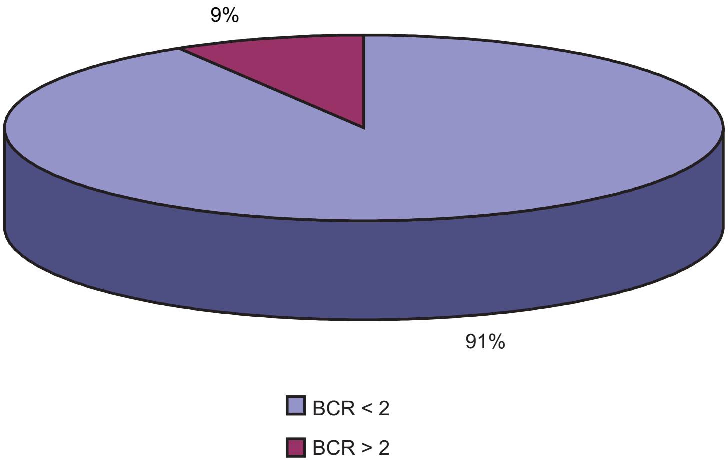
Socioeconomic impacts. The watershed development technologies aimed not only to conserve the natural resources but also to improve the socioeconomic conditions of the rural people who depended on them for their livelihoods. The impact of various watershed treatments is however widespread. The changes in various biophysical and environmental aspects will have significant impacts on the socioeconomic conditions of the people. Watershed development programs are designed to influence the biophysical and environmental aspects thereby bringing changes in the socioeconomic conditions (Deshpande and Rajasekaran 1997).

The socioeconomic indicators like changes in household income, per capita income and consumption expenditure, differences in employment, changes in lives of persons migrated, peoples' participation, household assets and wage rate at the village level were considered for the impact assessment.

The watershed intervention helped the rural farm and nonfarm households to enhance their income level. Evidence shows that the rural labor households in the treated villages derive Rs 28,732 when compared to Rs 22,320 in control villages, which is 28.73% higher in the Kattampatti watershed. Similarly, the per capita income is also relatively higher among households of watershed treated villages. The proportions of difference among households across villages worked out to 13.17% in the Kattampatti watershed and 70.44% in the Kodangipalayam watershed (Palanisami and Suresh Kumar 2005). In addition, increases in employment generation, social empowerment, and reduction in out-migration are also seen in many watersheds.

Overall economic impacts. Experience shows that watershed development activities have overall positive impacts on the village economy. It is essential to assess the impact of these watershed development activities using key indicators such as Net Present Value (NPV), Benefi Cost Ratio (BCR) and Internal Rate of Return (IRR). Though these indicators show the overall impact of watershed development activities, only a very few studies have quantified the benefits and arrived at the NPV, BCR and IRR. The reason for this is attributed to many, some of which are the following: (i) most of the evaluating agencies are not familiar with these techniques, (ii) inadequate data availability for quantifying benefits and costs, and (iii) non-familiarity with computer software. The overall impacts of watershed development activities in terms of NPV, BCR and IRR are discussed hereunder.

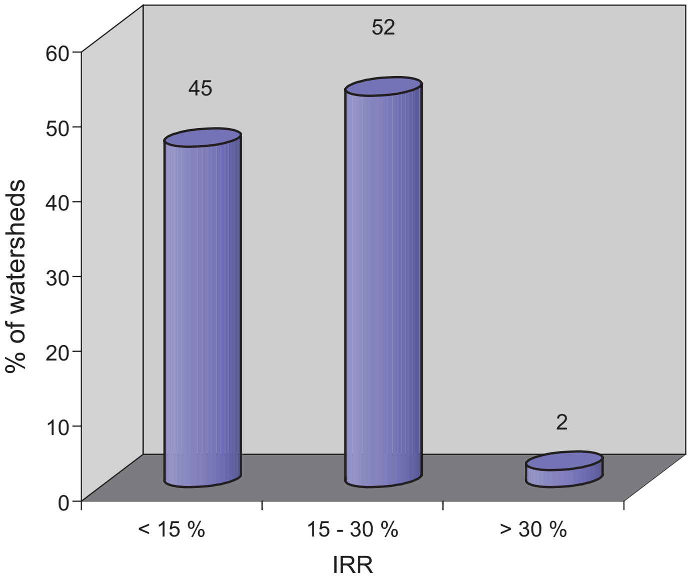
Figure 4. Distribution of watershed by BCR.



A few studies (Palanisami and Suresh Kumar 2005; Palanisami et al. 2002; Ramaswamy and Palanisami 2002; Palanisami et.al. 2002; Palanisami and Suresh Kumar 2006) have made an attempt to assess the overall impact of watershed development activities through BCR and NPV. The BCR which shows the return per rupee of investment ranged from 1.27 to 2.3.

The size of BCR also depends on the magnitude of benefits accrued due to the watershed development activities which in turn critically depend on the rainfall. The analysis also revealed that the BCR works out to more than 2 in around 9% of watersheds. About 91% of watersheds have a BCR less than 2. Similarly, about 45.45% of watersheds exhibit an IRR of less than 15%; 52.27% of watersheds have an IRR between 15 and 30% and only 2.27% of watersheds have an IRR higher than 30%.

Figure 5. Distribution of watershed by IRR.



It is evidenced that the BCR varies across regions and depends on the agroclimatic conditions. The financial analysis of the impact of watershed development indicates that the returns to public investment, such as watershed development activities, are feasible.

People's Participation in Watershed Management

Like all other development programs, the watershed development program is banking heavily on the participatory approach. Though the watershed development program envisages an integrated and comprehensive plan of action for the rural areas, people's participation at all levels of its implementation is very important. This is so because the watershed management approach requires that every piece of land located in the watershed be treated with appropriate soil and water conservation measures and used according to its physical capability. For this to happen, it is necessary that every farmer having land in the watershed accepts and implements the recommended watershed development plan. As the issue of sustainable natural resource management becomes more and more crucial, it has also become clear that sustainability is closely linked to the participation of the communities who are living in close association with these natural resources. This requires sustained effort in two important areas: (i) to inform and educate the rural community, demonstrate to them the benefits of watershed development and the fact that the project can be planned and implemented by the rural community with expert help from government and nongovernment sources, and (ii) to critically analyze the various institutional and policy aspects of watershed development programs in relation to participatory watershed management.

Experience from the evaluation study of 15 DPAP watersheds conducted in the Coimbatore District of Tamil Nadu, India shows that the overall community participation was found to be 42%. The participation was found to be 55, 44 and 27%, respectively, at planning, implementation and maintenance stages. This suggests there should be more community participation in watershed development programs. Similarly, overall contribution for work on private land was found to be 14.71%. It varied from a low of 7% for fodder plots to a maximum of 22% for horticulture and farm ponds. However, contribution in terms of cash/ or kind towards development of structures at common lands such as percolation ponds, check dams, etc., was found to be nil. The level of adoption of various soil and moisture conservation measures and their maintenance indicate that there is a wide variation in the level of adoption, with a low of 2.4% in the farm pond, 30.40% in summer ploughing, 36.80% in land leveling, and 44% in contour bunding. Follow-up activities by farmers are also found to be poor in most of the technologies, which account for 5.23% in farm ponds, 21.58% for contour bunding, etc. (Sikka et al. 2000).

Experience from DPAP and IWDP Watersheds in the Coimbatore District

Active participation of the watershed community at every stage of the watershed development program, e.g., planning, implementation and maintenance and follow-up is a must for effective development and sustenance of the watershed activities. This also helps improve their capacity-building, sense of responsibility, etc.

People's participation index (PPI) for planning (pre-implementation), implementation and maintenance (post-implementation) stages of the watershed development program in DPAP watersheds revealed that overall community participation was found to be low with an overall PPI of 42% (Table1). The PPI is found to be 55, 44 and 27%, respectively, at planning, implementation and maintenance stages. This suggests medium, low and very low levels of community participation at planning, implementation and maintenance stages of the watershed development program. This could be attributed to the fact that those who are not benefited from the project directly might not have participated in implementation and maintenance.

Community Participation in Watershed Development Activities

Community participation can be judged based on their contribution/involvement in terms of giving their time to the project and their contribution in cash/or kind towards works, both on development and management of private and common property resources. It is evident that the community members of watersheds have contributed in cash and kind towards the works on private lands. Overall, their contribution for works on private land was found to be 14.71% (Table 2). It varied from a low of 7% for fodder plots to a high of 22% for horticulture and farm ponds. Overall, this can be considered good. However, contribution in terms of cash and/ or kind towards development of common property resources such as percolation ponds, check dams, etc., is found to be nil.

Table 1. People's, participation in the DPAP watersheds of the Coimbatore District of Tamil Nadu.

Level of participation	Peoples' participation (number)		
	Planning	Implementation	Maintenance
Low	45	79	98
	(36)	(63)	(78)
Medium	52	32	22
	(42)	(26)	(18)
High	28	14	5
	(22)	(11)	(4)
Total	125	125	125
Overall PPI (%)	55	44	27
Level of participation	Medium	Low	Very low

Note: Values in parentheses indicate percentage of the total.

Table 2. Community participation for watershed development activities in the DPAP watersheds of the Coimbatore District of Tamil Nadu.

	Contribution (%)		
Name of activity	Cash	Kind	Total
Contour bunding	10	3	13
Land leveling	10	3	13
Summer ploughing	10	4	14
Vetiver plantation	10	2	12
Farm pond	15	7	22
Horticulture plantation	12	10	22
Fodder plots	5	2	7
Total	12.57	4.44	14.71

Adoption of Soil and Moisture Conservation Measures

The level of adoption of various soil and moisture conservation measures and their follow-up activities by farmers can also be considered as a combined effect of awareness, involvement in the program and contribution. The result indicates that there is a wide variation in the level of adoption, with a low of 2.4% in farm pond, 44% in bunding, to a high of 92% for horticultural plantation (Table 3). Follow-up activities by farmers are also found to be maximum (98%) in horticultural plantations, followed by summer ploughing (66%) and minimum in farm ponds.

Table 3. Level of adoption of soil and moisture conservation measures in the DPAP watersheds of the Coimbatore District of Tamil Nadu.

Activity	Rate of adoption		Maintenance (%)
	Frequency (N=125)	Percentage	
Land leveling	46	36.80	52.12
Bunding	55	44.00	21.58
Summer ploughing	38	30.40	65.76
Crop demonstration	25	20.00	25.36
Farm pond	3	2.40	5.23

People's Participation in Training and Exposure Visits

Experience from the IWDP watershed implemented in the Coimbatore District reveals that the number of participants who attended the training program varied from 60 to 93%, while the number of respondents who did not attend the training program varied from 7 to 40%. In the majority of the watersheds the total number of participants who attended the training exceeded 80% indicating the interests shown by the beneficiaries in attending training sessions and gaining technical knowledge.

Table 4. Participation in training and exposure visits in the IWDP watersheds of the Coimbatore District.

Particulars	Attended	Not attended	Total
User group training	142	38	180
	(78.9)	(21.1)	(100.0)
Exposure visits	83	187	270
	(30.74)	(69.26)	(100.00)

Note: Values in parentheses indicate percentage of the total.

Of the total respondents, nearly 31% attended the exposure visits and gained knowledge. Among the members who attended the exposure visits nearly 94% found the visits to be very useful. Therefore, it is suggested that a larger number of exposure visits covering different successful watershed models, community nurseries and research institutes involved in watershed development research may be organized. This will help gain knowledge regarding recent technical know-how and benefits of various watershed treatment activities among the members.

Factors Influencing People's Participation

A recent study indicates that the household contribution towards watershed development and maintenance is influenced by various household-level and supra-household-level factors (Suresh Kumar and Palanisami 2009). The factors such as number of workers in the farm family, number of wells owned by the farm households, distance between the farm and the rainwater harvesting structures are found to significantly influence the household contribution. Similarly, the supra-household-level factors such as the extent of social homogeneity as represented by caste at group level and the type of watershed technology positively and significantly influence household contribution.

Drivers of Success

Watershed development has been conceived basically as a strategy for protecting the livelihoods of the people inhabiting the fragile ecosystems experiencing soil erosion and moisture stress. The aim has been to ensure the availability of drinking water, fuelwood and fodder and raise income and employment for farmers and landless laborers through improvement in agricultural production and productivity (Rao 2000).

Most of the watershed development programs being implemented in the state aimed at (i) promotion of economic development of the village community which is directly or indirectly dependent on the watershed through optimum utilization of the natural resources of the watershed (land, water, vegetation) that will mitigate adverse effects of drought, (ii) employment generation and development of the human and economic resources of the watershed, and (iii) encouraging restoration of ecological balance in the watershed through sustained community action.

Experience from various impact assessment studies conducted in the state revealed that there is significant impact on soil and water erosion control, soil moisture conservation, water resources development, cropping pattern and increase in yield. The watershed development has also produced desired results in terms of improvement in socioeconomic conditions and the environment.

There are several reasons for the successful implementation of watershed development activities in the country. They include physical and agroclimatic conditions of the watershed villages like rainfall, soil type and hydrogeological features. In addition, some of the administrative and institutional issues such as guidelines for effective watershed development, role of different organizations like the state and central governments, line departments, and type of PIAs play a crucial role in implementing watershed development activities.

Future Directions

Watershed development programs not only protect and conserve the environment but also contribute to livelihood security. With the large investment of financial resources in the watershed program, it is important that the program becomes successful. For achieving the best results, people should be sensitized, empowered and involved in the program. Local community leaders and stakeholders should be necessarily motivated about conjunctive use of water, prevention of soil erosion, etc., through various media. The stakeholders at different levels should be involved at various stages of project activities, planning and implementation with the ultimate objective of sustainability. In addition to the above, strengthening of community organizations within the watershed, implementation of the planned watershed management activities, encouraging linkages with other institutions and initiating groups towards formation of apex bodies will help motivate the people and make the watershed development program a people's movement.

Given the increasing demand for a watershed program by the community, it is difficult to provide adequate funding for all locations. Hence, the development and adoption of a Decision Support System (DSS) to promote the watershed investment is highly warranted.

As the impact assessment of watershed development has been felt crucial, a general framework has to be developed and personnel trained who are involved in the watershed development impact assessment. Experience shows that most of the impact evaluation studies depended on primary data collected from the stakeholders through participatory rural appraisal techniques and interviews, supported by secondary data. Developing a framework, selection of the right approach and methods of impact assessment, and identification and use of indicators will enable the process of impact assessment to be sophisticated. Establishing a proper institutional mechanism in a multidisciplinary approach will be a viable step in impact assessment. Panel databases should be created for the watersheds in different agroecological regions for proper evaluations.

Redefining the Quantification of Benefits due to Watershed Development Is Warranted at Present

Upstream and downstream conflicts. Being a common property resource, treatments in watersheds generate various positive externalities. Conflicts arise between downstream and upstream farmers in sharing benefits and making investments. Thus, care should be taken when quantifying the cost and benefits for impact assessment in watersheds.

Zone of influence. As the rainwater harvesting structures are the main structures which generate various positive externalities, quantifying benefits from these structures like percolation ponds, check dams and farm ponds assumes importance in impact assessment. When quantifying the benefits, determining the zone of influence is very crucial and a challenge to the evaluators. For instance, the zone of influence of a percolation pond varies from 300 meters to 400 meters downstream and 200 to 250 meters upstream. Similarly, the zone of influence of tanks as a groundwater recharge structure varies from 4 to 5 km downstream based on the size of the tank. Thus, one must be careful in determining the zone of influence when quantifying the benefits from the rainwater harvesting structures.

Natural and artificial recharge. The rainwater harvesting structures like percolation ponds, check dams, tanks and farm ponds are expected to increase the groundwater recharge in the wells located in the zone of influence. Enough care should be taken to segregate the natural and artificial recharge. Experience shows that the total groundwater recharge in wells due to various structures is found to be around 30% of total recharge. However, the natural recharge without any rainwater harvesting structures is reported to be about 10%. Thus, the net recharge due to rainwater harvesting structures is only 20%. Thus, while evaluating the impact of recharge structures, care should be taken to account for the natural and artificial recharges (Palanisami and Suresh Kumar 2006).

Addressing all these issues will help achieve sustainability in watershed management in the state and elsewhere.

Conclusion and Policy Implications

Today, watershed development has become the main intervention for natural resource management and rural development. Watershed development programs not only protect and conserve the environment but also contribute to livelihood security. The importance of watershed development as a conservation program is being recognized, not only for rain-fed areas but also for high rainfall areas, coastal regions, and the catchments areas of dams. With the large investment of financial resources in the watershed program, it is important that the program becomes successful. Experience shows that the watershed development programs have produced desired results and there are differences in their impacts. Hence, the watershed impact assessment should be given due importance in the future planning and development programs.

Watershed development activities have a significant impact on groundwater recharge, access to groundwater and, hence, the expansion in irrigated area. Therefore, our policy focus must be the development of these water harvesting structures, particularly percolation ponds wherever feasible. In addition to these public investments, private investments through the construction of farm ponds may be encouraged as these structures help in a big way to harvest the available rainwater and, hence, groundwater recharge.

Watershed development activities have altered crop patterns, increased crop yields and crop diversification and thereby provided enhanced employment and farm income. Therefore, an alternative farming system combining agricultural crops, trees and livestock components with comparable profit should be evolved and demonstrated to the farmers. Once the groundwater is available, high water-intensive crops are introduced. Hence, appropriate water saving technologies like drip should be introduced without affecting farmers' choice of crops. The creation and implementation of regulations in relation to depth of wells and spacing between wells will reduce well failure, which could be possible through Watershed Associations. The existing NABARD norms such as 150 meters spacing between two wells should be strictly followed.

Therefore, the future strategy should be a movement towards a balanced approach of matching the supply-driven menu with a set of demand-driven activities. People's participation, involvement of panchayat raj institutions, local user groups and NGOs alongside institutional support from different levels, such as the Union Government, the State, the District and block levels should be ensured to make the program more participatory interactive and cost-effective. Convergence of various rural development programs in and around the watershed could be ensured to promote the holistic development of watersheds. For its continued success, the program should be economically efficient, financially viable, technically feasible and socially acceptable while ensuring equity. For sustainable development, regular and routine monitoring of environmental parameters is important as environmental enhancement increases the credibility and acceptability of the program.

Annex

Abstract of total number of watersheds in Tamil Nadu.

Name of district	No. of watersheds		No. of sub-water-sheds	No. of mini-water-sheds	No. of micro-watersheds			
	Full	Partial			Gr.I	Gr.II	Gr.III	Gr.IV
Kancheepuram	1	6	24	80	349	169	7	
Tiruvellor	3	3	11	47	107	165	170	116
Thiruvannamalai	2	10	27	86	302	409	213	8
Villupuram	2	6	34	74	367	273	156	
Cuddalore	2	6	35	126	441	274	73	15
Vellore	5	10	22	85	82	257	95	34
Dharmapuri	7	6	21	115	330	462	400	257
Coimbatore	2	4	22	28	127	638	436	84
Nilgiris	5	1	34	153	258	297	37	2
Erode	5	10	13	41	131	149	82	19
Salem	2	10	21	104	411	410		
Namakkal		7	12	37	105	202	144	113
Tiruchy	1	9	39	99	184	206	195	75
Perambalur		6	20	44	122	195	229	129
Karur	2	4	15	36	97	152	97	43
Tanjavur		5	28	15	28	93	413	182
Tiruvarur		4	9	49	328	104	0	
Nagapattinam		5	16	93	245	171	15	
Pudukkottai	2	7	19	70	216	161	41	13
Ramanathapuram	1	6	8	73	288			
Sivagangai	1	10	20	68	233	214	90	15
Madurai	2	4	14	123	424	358	92	
Virudhunagar		3	5	73	151	52		
Theni	2	1	7	229	547	295	53	
Dindigul	1	6	21	264	589	632	135	5
Tuticorin	3	4	37	103	676	279		
Tirunelveli	4	6	14	39	167	299	167	35
Kanyakumari	2	1	6	9	77	200	318	30
Total					7,382	7,116	3,658	1,175
Micro-watersheds								19,331

Source: GoTN 2002.

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Agenda of the Workshop

National Workshop on Strategic Issues in Indian Irrigation

International Water Management Institute and the Challenge Program on Water and Food project on "Strategic Analyses of India's National River Linking Project"

April 7-8th 2009, Amaltas Hall , India Habitat Centre, New Delhi

Agenda-Day 1

Session I	**Future of Irrigation: Strategic Issues** *Chair: Dr. Colin Chartres*
09:00-09:30	Registration
09:30-09:40	1. Welcome *Dr. Madar Samad, Reginoal Director, South Asia, IMWI*
09:40-10:00	2. Keynote Speech: Water Management Challenges: International Perspective *Dr. Colin Chartres, Director General, IMWI*
10:00-10:20	3. Keynote Speech: The River Linking Project for India's Irrigation Future *Shri A.D. Bhardwaj, Director General, National Water Development Agency, India*
10: 20-10:40	4. Keynote Speech: Meeting India's Irrigation Future: Challenges *Shri A.k. Bajaj, Chairman, Central Water Commission, India*
10:40-11:00	5. Inaugural Speech: Irrigation for India's Agricultural Future *Prof. M.S. Swaminathan, Chairman, M.S. Swaminathan Foundation*
11:00-11:10	6. Agenda of the Workshop: *Dr. Upali Amarasinghe, IMWI*
11:10-11:30	**Tea/Coffee**
Session II	**Benefits of Irrigation Water Transfers** *Chair: Dr. Madar Samad, International Water Management Institute*
11:30-13:15	1. Irrigation Planning in Uncertain Environments: Changing Dynamics of Indian Agriculture *Dr. Tushaar Shah, IMWI* 2. Ex-ante Analysis: Financial Benefits of Water Transfers in Peninsular Links of the River Linking Project *Dr. Upali Amarasinghe, IMWI*

3. Discussant – Dr. Ashok Gulati, Head IFPRI, Asia Program
4. Discussion

13:15-14:15 **Lunch**

Session III **State of Irrigation of States**
Chair: Shir Anil D. Mohile, Former Chairman, Central Water Commission

14:15-16:00

1. State of Irrigation in Tamil Nadu: Trends and Turning Points
   Dr. R. Sakthivadivel, Consultant (Former IMWI Research Fellow)
2. Future of Irrigation in Tamil Nadu and Investment Options
   Dr. K. Palanisami, Director, IMWI-TATA Policy Program
3. Discussant-*Dr. Alok Sikka, Technical Expert (Watershed Development), National Rainfed Area Authority*
4. Discussion

16:00-16:15 **Tea/Coffee**

Session IV **Lessons for new irrigation Projects**
Chair: Dr. Ramaswamy Iyer, Visiting Professor, Centre for Policy Research, New Delhi

16:15-18:15

1. Managing Rehabilitation and Resettlement of Displaced Population: Lessons from Selected Hydro Projects
   Dr. Madar Samad, IMWI
1. Managing Waterlogging and Salinity: Lessons from the IGNP
   Dr. Bharat Sharma, IMWI
2. Planners Propose, Farmers Dispose: Salvaging the Sardar-Sarovar Project
   Dr. Tushaar Shah, IMWI
3. Discussant – *Shri Himanshu Thakker, Coordinator, South Asia Network on Dams, Rivers & People*
4. Discusion

Agenda-Day 2-April 8, 2009

Session V **Meeting Increasing Water Demand: Potential from Demand Management Strategies**
Chair: Prof. Kanchan Chopra, Director Institute of Economic Growth

9:30-11:15

1. Demand Management Strategies in Irrigation: Synthesis of NRLP Research
   Dr. Rathinasamy Maria Saleth, Madras Institute of Development Studies
2. Water Pricing as a Demand Management Option: Potentials, Problems and Prospects
   Dr. Ratna Reddy, Director, Livelihoods and Natural Resource Management Institute
3. Discussant – *Dr. L. Venkatachalam, Madras Institute of Development Studies*
4. Discussion

11:15-11:30	**Tea/Coffee**
Session VI	**Meeting Increasing Water Demand: Potential from Water Productivity Improvements** *Chair: Shri. S. Gopalakrishnan, Secretary General, ICID*
11:30-13:15	1. Potential Pathways for Improving Water Productivity in India: Synthesis of NRLP Research *Dr. Dinesh Kumar, Director, Institute for Analysis of Resources and Policy* 2. Increasing WP with Multiple Water Use: Some Case Study Results *Dr. Alok Sikka, Technical Expert (Watershed Development), National Rainfed Area Authority* 3. Discussant-*Prof. A. Narayanamoorthy, Director, Centre for Rural Development, Alagappa University, Tamil Nadu* 4. Discussion
13:15-14:15	**Lunch**
Session VII	**Meeting Increasing Water Demand: Augmenting Water Supply through Artificial Groundwater Recharge** *Chair: Dr. J. S. Samra, Chief Executive Officer, National Rainfed Authority*
14:15-16:15	1. Hydro-Climate Change and Food Security: India's Storage Challenge *Dr. Tushaar Shah, IWMI* 2. Assessment of Dug-Well Recharge Programs in India: Synthesis of NRLP Research *Dr. Sunderrajan Krishnan, INREM, Anand* 3. Virtual Water Trade as an Option *Mr. Shilp Verma, UNESCO-IHE and IWMI* 4. Discussant – *Dr. Bharat Sharma, International Water Management Institute* 5. Discussion
16:15-16:30	Conclusions Dr. Upali Amarasinghe
16:30	**Tea/Coffee**

Participants

No	Participant	Designation/Institute Affiliation
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Related Publications

Amarasinghe, U. A.; Shah, T.; Malik, R. P. S. (Eds.). 2009. ***Strategic analyses of the National River Linking Project (NRLP) of India, Series 1: India's water future: scenarios and issues.*** Colombo, Sri Lanka: International Water Management Institute (IWMI). 403p.

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