IWMI'S RESEARCH ACHIEVEMENTS, 1995 TO 1999

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I
Introduction

Since late 1995, IWMI has given the highest priority to strengthening its research program. This has involved recruitment of new staff, concentration of resources on research, encouragement of refereed publications by staff, and a major reorientation of the research program. By late 1999 IWMI feels it has had considerable success in creating a strong research culture and program at IWMI; and that this strength can now serve as a good foundation for expanding applied and outreach activities in partnership with interested developing countries.

When the Institute was established as the International Irrigation Management Institute (IIMI), the focus was almost entirely on irrigation management. Some attention was paid to on-farm irrigation management, for example irrigation of other field crops in rice-based systems; but most effort went into understanding and improving “main system management” – what Wade and Chambers (1980) referred to as the ‘blind spot’ in irrigation management. Along with this went a strong program on indigenous farmer-managed irrigation and irrigation management transfer processes. Most of the work was supported by bilateral donors in specific countries. Therefore, not surprisingly, the Institute emphasized applied research and capacity building, with relatively little strategic or upstream research. Productivity in terms of refereed publications was low. On the other hand, many partner countries cooperated actively, and evaluated most of the work positively in terms of its usefulness and impacts.

Upon joining the CGIAR in 1992 the Institute expanded its mission to focus on ‘irrigated agriculture,’ though in practice this did not lead to any major changes in resource allocations. The themes remained similar to what they had been: main system management, performance of irrigation systems, and policies and strategies for promoting local management of irrigation. There was however little change in the balance between applied country level work and capacity building on the one hand, and strategic research on the other. The External Program and Management Review (TAC 1994) expressed strong concern about the weakness of strategic research while noting that country level satisfaction with the Institute’s impacts remained high. The research record was perhaps better than most believed at the time, but most of the important findings were never published in scientific journals (Merrey 1997).

Beginning in late 1995, while continuing to place the highest priority on irrigation, IWMI’s program began changing drastically, as it adjusted to a new research paradigm based on integrated water resources management in a river basin context. New themes have come to drive the research program: performance assessment based on the productivity of water (“crop per drop”) not land; the river basin paradigm which underlies most of our work on technical and institutional problems; global studies on water and food security; application of new information technologies such as remote sensing; work on human health and environmental issues; and a strong focus on poverty and gender.

Our research program is organized around four global programs or 'research groups[1].' This four-program structure has remained stable, but there have been important adjustments in their names and content as we worked out the implications of the new IWMI paradigm. These adjustments are reflected in the annually updated three-year rolling medium term plans (MTP) submitted to the CGIAR TAC. Much of the actual work is done through multidisciplinary teams whose members are drawn from two or more groups. There has been a geographical focusing of our resources as well. In the early 1990s we had about 10 country programs with residential staff, few of which had sufficient resources to do significant research. Today we have three residential programs, Pakistan, Sri Lanka (headquarters), and Mexico until mid-2000; there is one staff member posted to WARDA in West Africa, and some countries in Africa and Asia have part-time or nationally recruited representatives. This concentration has enabled us to form strong research teams to work on specific issues.

Section II presents what IWMI regards as key highlights of its record over the past five years. Sections III through VI present more detailed results and achievements of each of the four global research programs or groups, prepared by the leaders of these programs. Section VII describes some of the highlights of the first phase of the System Wide Initiative on Water Management (SWIM). The final section (VIII) provides insight into some of our major national outreach programs, again prepared by the leaders of these programs.

The reader may also wish to refer to a special issue of the *International Journal of Water Resources Development,* March/June 1999**: Research from the International Water Management Institute**. The fourteen articles provide an excellent compendium of the major issues being addressed at IWMI.

[1] In the draft Strategy Paper (IWMI 1999a), we have proposed to change the designation from "Global Research Programs" to "research groups." This change has not yet been approved by the Board of Governors.

II
Highlights of IWMI's Research, 1995-1999

Introduction

In the 1990s the world has begun to experience a rapidly growing sscarcity and competition for water. Water scarcity today stands as perhaps the largest single threat to food security and to achieving the CGIAR mission of poverty eradication. A host of new problems are emerging. These include:

- a reduction in water allocated to irrigated agriculture;
- falling ground water tables in the semi-arid regions and some of the major breadbaskets of the world;
- pollution affecting the health of crops, livestock, and humans;
- growing poverty particularly in rain fed and marginal areas.

Solving these and other related problems will require changes in the way we manage our water resources. New policies, technologies, and institutions will be needed.

IWMI over the past five years has turned its attention to research to meet the challenges posed by this new environment of scarcity. In this section we highlight research achievements that are dealt with in more depth in the following sections. This section is not a 'synthesis' or summary of what follows; rather it highlights several achievements that IWMI regards as particularly important.

Global Water Scarcity: The Dimensions of the Problem

A study projecting water supply and demand for 118 countries to the year 2025 sets forth geographic, temporal, and social dimensions of the water scarcity problem (Seckler et. al 1998; Seckler et. al. 1999). This study, the first of its kind, estimates that 2.7 billion people, one third of the anticipated 2025 world's population, will live in regions facing severe water scarcity in the first quarter of the next century. The most severely affected regions will be the semi-arid regions of Asia, the Middle East, and Sub-Saharan Africa, but even many well-watered areas will have to adjust to the pressures of competition.

This study has been followed up by the development of an interactive policy dialogue model, PODIUM. This model estimates future food needs and water requirements, both globally and country-wise, taking into consideration various scenarios of population, diet, climate, yields, trade, and water use for irrigated agriculture and other sectors. PODIUM has been particularly useful in stimulating policy discussions at the country level. Through PODIUM and continuing research on water supply and demand, IWMI has been making important contributions to the development of the World Water Vision 2025 to be discussed at the Second World Water Forum in the Hague in March 2000.

New Concepts: The IWMI Water Resources Paradigm

Traditional analyses of irrigation performance and efficiency can mislead planners and policy makers, especially as water availability at the river basin level becomes the primary constraint to agricultural production. IWMI cannot claim intellectual property rights over the concepts encompassed by the title of this section. Our contribution lies in promoting approaches we feel are essential for improving irrigation efficiency and increasing water productivity. However, it is the acceptance of these concepts that defines IWMI's research focus on new methodologies, tools, and approaches to water resource management described in the sections which follow.

The "IWMI Paradigm" – a phrase coined by others, not by IWMI – is based on the concept of integrated water resource management (IWRM) but emphasizes the need to understand irrigation efficiency, water utilization, and water productivity at the river basin as well as the farm and system level (Seckler 1996; Perry 1999,). Irrigation efficiency typically relates the volume of water beneficially used (i.e., crop evapotranspiration) to the amount of water *diverted* to a use. However, increases in efficiency at the farm level may not lead to increases in efficiency at the basin level. This is because measurement of efficiency at the basin level takes into account the use of *return flows* from seepage, percolation, and surface runoff traditionally counted as "losses" at farm and system level. It thus takes into account both on-site and off-site impacts.

As water resources are exploited over time, river basins become "closed" during all or part of the year. That is to say, no more water of usable quality is flowing to the sea. It is important to assess whether a basin is "open" or "closed". The closing of a basin marks the beginning of water scarcity and all that this implies for basin management.

The focus on basin level water resource efficiency draws attention to the competition for water among sectors and the need understand the interrelationship between surface and ground water. The canal system is often a major source of groundwater recharge, but overexploitation of groundwater and falling ground water tables is becoming an all too common problem. Reforms are needed in many national level irrigation and water resource bureaucracies to address these issues.

Another critical component of the new paradigm concerns water productivity. The now familiar phrase *crop per drop* emphasizes the need to treat the productivity of water (e.g. yield per cubic meter of water) as seriously as we have traditionally treated productivity of land (e.g., yield per hectare). Indeed, in water-scarce areas improving water productivity should take precedence over improving land productivity.

New Methodologies: Water Accounting

Major emphasis has been given to the development and testing of a water accounting framework to measure the use and productivity of water at field, system, and basin level (Molden 1997). The concept of beneficial use of irrigation water or *basin efficiency* was derived to replace traditional concepts of efficiency (Molden and Sakthivadivel 1999). The procedures, including the use of a consistent set of definitions, is being applied in collaboration with national partners in large and

small basins around the world. A comparison has been made between two irrigation systems in the semi-arid regions of India and Pakistan and a system in the more humid regions of Sri Lanka. The results showed that in the former (compared to the latter) the beneficial use of irrigation water or *basin efficiency* was very high (Molden, Sakthivadivel and Habib 1999). In China in collaboration with IRRI and WUHEE (Wuhan University of Electrical and Hydraulic Engineering) water accounting procedures are being used to determine how much water is being saved in a large sub-basin level due to the on-farm water management practice of alternate wetting and drying. The division of river basins into “hydronomic zones” helps to define areas in the basin where increases in water saving at the farm-level will lead to greater basin level efficiency (Molden, Sakthivadivel, and Keller 1999).

Throughout its existence, IWMI has been a leader in developing and applying methodologies for assessing irrigation performance. With increasing scarcity of water, measuring the productivity of water resources is arguably one of the most important indicators of performance. With the emphasis on crop productivity or crop output per unit of water, IWMI has developed a standard set of performance indicators and compared 27 systems scattered across Asia, Africa, and Latin America (Molden et. al. 1998, Sakthivadivel et. al 1999a). Performance indicators measured before and after intervention have also been used to quantify the impact of rehabilitation and organizing farmers in the Gal Oya Left Bank Irrigation Scheme in Sri Lanka (Murray-Rust, Sakthivadivel and Amerasinghe 1999).

Ultimately decisions regarding the allocation of water should take into consideration the social and economic value of water in competing uses. Treating water as an economic good has mixed impacts since water, depending on the situation, is treated as both a public and private good and it is of course a necessity of life (Perry, Rock and Seckler 1997). Beginning with a study of the multiple uses of water in Kirindi Oya, Sri Lanka, IWMI has been developing methodologies for valuing the various uses of water (Bakker, et. al. 1999; Renwick et. al. forthcoming).

New Tools: Information Technologies

IWMI researchers make increasing use of advanced information technologies. Remote sensing techniques combined with geographic information systems (GIS) and hydrological modeling have become powerful tools for basin level management and performance assessment. *Information technologies* are to improvement of water basin management what *biotechnologies* are to crop improvement. Before these new information technologies became available, the scale of water research was constrained in its ability to deal with complex systems spread over large areas. New information technologies facilitate the analysis of large areas such as river basins and irrigation systems and the testing of alternative interventions through computer simulation and modeling.

At the **global** level a *World Water and Climate Atlas* has been developed by IWMI in collaboration with the University of Utah Climate Center and the Climatic Research Unit of the University of East Anglia. The IWMI Atlas is a growing collection of a wide range of water, climate and other GIS gridded data products at various temporal and spatial resolutions. The use of a *synthesizer* makes it possible to interface data from other sources with the Atlas. Since the release of the Atlas, IWMI has received regular requests for copies of the *synthesizer* compact

disc (CD) and associated data sets. These data are also regularly downloaded from the IWMI web site (www.cgiar.org/iwmi). Recently IWMI has used the *synthesizer* together with gridded data from the University of East Anglia to produce monthly moisture availability indices for India and Pakistan. The results show clearly in which areas there is a need for irrigated agriculture, where supplementary irrigation of rain fed agriculture is important, and where there is a need to focus more on drainage problems.

At the **basin and systems** level information technologies coupled with modeling are being used for: (i) irrigation systems performance, (ii) various modeling exercises, and (iii) evapotranspiration estimates. Remote sensing studies have been carried out in partnership with the National Remote Sensing Agency of India. In the 1.2 million hectare Bahkra irrigation system in India, combined measures of yield and crop consumptive use gave the productivity of crop evapotranspiration for the whole command area (Bastiaanssen et. al. 1999a; Sakthivadivel et. al. 1999b).

The use of models has accelerated with the increased attention to basin level management. In Turkey models have been used to investigate alternative basin development scenarios in the Gediz Basin. They have also been used to measure the impact on agricultural production on changing water allocations to protect the Kis Cenneti wetland area, important as a bird habitat (Kite and Droogers 1999b; Voogt et. al. 1999). In Mexico IWMI and IFPRI scientists are integrating hydrological and economic models to investigate water allocation decisions and management alternatives in the Rio Lerma Basin (Scott and Garces-Restrepo 1999).

Negotiations on water allocation and water rights, and designs for improvements in water use require good data. Unfortunately, institutions are often unwilling to share information, because they believe some advantage in negotiations may be lost. This situation is rapidly changing with the increasing amount of information available from the internet and from remote sensing. There is potential for much more transparency in discussions between stakeholders, and a potential for better agreements between parties. IWMI has noted these trends (Perry, 1999), and has shown how basin modeling could be achieved with publicly available data sets (Lacroix, Kite and Droogers, forthcoming). We have also shown that remote sensing can be used for performance assessment in a cost-effective manner: costs of US $0.01-0.03 per ha for crop consumptive use of water and crop yields on a seasonal basis in a 1.2 million ha system (Bastiaanssen et al. 1999a; Sakthivadivel et al. 1999b).

In order to promote the wider application of computer-based decision-support tools among irrigation agencies, IWMI together with CEMAGREF and the Land and Water Division of FAO have formed the Information Technologies for Irrigation Systems (ITIS) network. The network, consisting of researchers and practitioners, meets approximately once a year to discuss and promote the application of IT to improve decision making in irrigation management (ITIS, 1998).

A New Research Program: Health and Environment

The closing of river basins and growing scarcity of water reduces both the quantity and quality of water available which in turn puts pressure on the health of humans, animals, and plants and on

the environment. IWMI's research attempts to improve the understanding of the linkages between irrigated agriculture, environment, and health and to develop water management methods that will improve health or mitigate health hazards and environmental degradation.

Salinity is a major threat to the sustainability of irrigated agriculture worldwide. IWMI has contributed to an understanding of the problem and to identifying ways to address the issue. Kijne (1996) and Sakthivadivel et. al. (1999b) reviewed previous studies and performed detailed analyses of water and salt balances in Pakistan and Northwest India. The studies in Pakistan raise serious questions about the possibility of managing the macro-level salt balances in the long term. Modeling studies at the farm level demonstrated that even using deficit irrigation it is possible through improved on-farm management to manage water logging and salinity (Prathapar and Quereshi 1999). IWMI will continue to perform salt and water balances at the basin level and to understand how basin and system level management practices can help farmers overcome problems of salinity.

A study to assess the feasibility of reducing the transmission of malaria through water management in natural streams and irrigation canals was carried out in a watershed in North Central Sri Lanka from 1994 to 1998 (Konradsen et. al. 1998; Matsuno et. al. 1999). A correlation was established between the water levels in the stream, numbers of mosquitoes (the vector for transmission), and human malaria cases reported. A management routine where water was released from an upstream reservoir for two days at ten-day intervals dramatically reduced the mosquito population and incidence of malaria. Further research is being undertaken in India, Kenya, Sri Lanka, and China to assess the change in the incidence of malaria using alternate wetting and drying water-saving techniques in paddy rice fields.

Irrrigation water is extensively used for non-agricultural purposes including domestic purposes. In Kirindi Oya, Sri Lanka it was found that only about 15 percent of the irrigation water was used in crop production (Bakker et. al. 1999; Meinzen-Dick and Bakker 1999). This study of the multiple uses of water has led to a focus on water quality and its effect on human health, agricultural production, and the environment.

In large areas of Pakistan people depend on irrigation water for all of their requirements including drinking water. The domestic use of irrigation water has been the subject of baseline surveys on disease incidence, water quality, availability of water, sanitation, and hygiene practices. The results will guide the implementation of interventions to improve the drinking water supply and sanitation of the people in the irrigated areas.

In Mexico a study has just been completed in one of the sub-basins of the Rio Lerma that assesses the effect of using untreated waste water from an urban area in crop production. (Scott, Zarazua and Levine, forthcoming). Contrary to expectations the farmers prefer the waste water as it provides ample nutrients making the application of chemical fertilizers unnecessary. In this instance the waste water carries no heavy metals and is thus not a threat to human health. An ordinance in Mexico requires cities to filter their waste water which will result in a significant cost to farmers.

New Insights: Institutional Reforms

Scientists conducting research on water management have long been frustrated by the lack of interest among irrigation agencies in adopting improved management techniques. However, with the growing scarcity and competition for water and budget constraints facing many countries, there is mounting pressure for institutional reforms.

Irrigation management transfer (IMT) involves the transfer of authority for management from government schemes to private user groups. IMT has become a major policy focus on many countries around the world, but there is enormous variation in the scope, speed of implementation, and level of required support to make IMT successful. A major conference on IMT co-sponsored by IWMI and FAO was held in Wuhan, China in 1994 (Johnson, Vermilllion and Sagardoy 1995) IWMI has analyzed IMT experience in Mexico (Johnson 1997; Kloezen, Garces-Restrepo and Johnson 1997), Columbia (Vermillion and Garces-Restrepo 1998) and Sri Lanka (Samad and Vermillion 1999a & b) and tracked progress in several other countries. Even in Mexico where the reforms have been most extensive, there is as yet little evidence that reforms have led to increased water productivity. FAO and IWMI have published a *Guidelines for IMT* based in large part on the past decade of IWMI's research (FAO and IWMI 1999).

There have been a number of other IWMI studies focusing on institutional development and reforms. These include work in Egypt (Perry 1995; Merrey 1998), Niger and Burkina Faso (Abernethy and Sally 1999), Pakistan (Bandaragoda and Rehman 1998; Bandaragoda 1998; 1999), and Sri Lanka. With the exception of Egypt, each of these studies covered a period of about five years and emphasized local participation. It is worth commenting briefly on the 'action research' programs in Pakistan and Sri Lanka.

In the Punjab and Sind Provinces in Pakistan 200 water user associations were established at the tertiary level and four water user federations at the secondary canal level (Bandaragoda 1999). The research demonstrated that perceived constraints to farmer organization – illiterate farmers, pressure from big landowners, and a hierarchical society – could be overcome. The results of this pilot study has encouraged the higher political and policy planning levels in Pakistan and the donor agencies to replicate these institutional reforms on a wider scale.

The Shared Control of Natural Resources (SCOR) project was designed to assist the Government of Sri Lanka to identify, develop, and field test novel management models for increasing the sustainable productivity of natural resources – mainly land and water – in a watershed context (SCOR 1999). Research was conducted in two watersheds in northern and southern Sri Lanka with the emphasis on shared control by local user groups and local branches of government agencies. The specific mechanisms which SCOR employed to carry out these objectives included establishment of local resource user groups, the use of a cadre of catalysts, financial and technical support through sub-watershed based mini-projects, market oriented farmer companies, and a variety of arrangements for sharing resource management responsibilities and benefits between state and local people. Through its support to farmer organizations and innovations in organizational forms, SCOR has helped the government consider new strategies for development and new income options for farmers.

Despite the trend toward devolution of irrigation management to local user groups, the competition for water and shift toward a river basin focus suggest that there is likely to be more rather than less government involvement in water policy in the future than in the past (Perry 1999). There are important areas, for example, the safety of dams, flood control, drought planning, water quality regulation, and groundwater depletion, where management at the basin, province, or national level is of great importance. There is a growing need for water boards or departments which can deal with the allocation of water for irrigation and for other uses. IWMI is currently studying an initiative that has led to the creation of a *water council* in Sri Lanka.

A New Research Topic: Gender and Poverty

IWMI's research on gender issues began in the early 1990s. Case studies of women's roles in irrigated agriculture were conducted in Nepal, Burkina Faso, Bangladesh, and later Mexico. The resulting research reports and articles in international journals were widely cited (Zwarteveen 1995a; 1995b; 1997a; and 1997b; Zwarteveen and Neupane 1996). In 1996 Margareet Zwarteveen received the ICID Award for Young Professionals for her work.

The 1994 EPMR Team (TAC 1994) recommended that the Institute expand its work in this area. In 1997 IWMI hosted an international workshop on *Women and Water* (Merrey and Baviskar, eds. 1998). This led to the recruitment of a gender specialist and the establishment of a Gender, Poverty and Water Project. The overall research aim is to identify policies to provide poor women and men with access to water. Comparative field research has been initiated in Pakistan, Nepal, India, Sri Lanka, South Africa, and Mexico.

The general pattern that emerges from IWMI's studies is that women are heavily involved not only with acquisition of water for domestic use but also in most instances with irrigation. However, women are rarely involved in water users associations where issues related to the allocation of water are discussed. Women who have access to land and water and other assets often make more productive use of them than men (Van Koppen, 1999a, 1999d).

New Partnerships: Intercenter Collaboration

The Technical Advisory Committee (TAC) of the CGIAR designated IWMI as the convening center for the System Wide Initiative on Water Management (SWIM). IWMI's research has focused primarily on the system and river basin level. There was thus an urgent need to collaborate with other commodity and resource centers and with IFPRI. Phase I of SWIM has drawn more and more CGIAR scientists into the dialogue on water scarcity and has expanded research on water beyond crops to include trees, fish, wildlife, and other uses and users. The SWIM paper series has generated a great deal of interest as reflected in particular by the request for publications and the number of downloads on the internet (SWIM 1999).

In Phase II SWIM collaborative projects are expected to be fully integrated into the agreed research agenda of the various centers involved and to receive funding through the usual process of submitting projects to donors. The first project in Phase II involves collaboration with IRRI, Wuhan University of Hydraulic and Electrical Engineering, and Zhejiang Agricultural University in studying the impact of water saving irrigation techniques in China. Other projects being

initiated include: (i) collaboration with ICLARM on studying the impacts of changes in the hydrological regime on the fisheries potential of the Cambodian portion of the Mekong River, and (ii) collaboration with IFPRI to develop an interface between economic and hydrological models to analyze water management and allocation problems in the Rio Lerma Basin of Mexico.

III
Irrigation and Water Resources Program

Background

It is generally recognized that new and innovative approaches are necessary to effectively manage the world's increasingly scarce water resources. A good knowledge and understanding of water availability and water use in countries, regions and river basins are essential. Methodologies to assess the performance of irrigation and water resource systems, including measurements of the productivity of land and water, constitute key components in this endeavor. They not only enable diagnosis and design of interventions but also help understand why certain interventions are more successful than others.

Much of the past work on irrigation performance has dealt with water delivery processes. While considerable progress has been made in developing and testing performance indicators for this purpose, new, integrated approaches are required when considering irrigation in the broader context of different uses and competition for water within basins. Greater emphasis has to be placed on measuring the productivity of water, and on seeking ways to assess the value of water in multiple uses and to improve basin water productivity. The notion of 'more crop per drop' has steadily gained acceptance as an appropriate way of expressing this paradigm.

More crop per drop can be achieved in a number of ways: (a) increasing crop production, (b) reducing water consumption, or (c) a combination of the above. Improvements in crop production can be realized through use of improved varieties, better agricultural practices including use of fertilizers, and by reducing water stress during key crop growth stages. IWMI hypothesizes that reliability of supply encourages greater farmer investment into crop production. Reducing water consumption necessitates better irrigation practices such as the application of limited quantities of water in the time and amounts needed to increase overall water productivity without adverse impact on crop yield. IWMI's attention is focussed on minimizing water used for crop production and on promoting better water management and agriculture practices with a view to improving crop production.

A major problem faced in operationalizing the IWMI paradigm is the absence of consistent methodologies and performance indicators to account for water and compute its productivity. Clear definitions of water productivity are required to enhance communication – which *crop* and which *drop* are we talking about? For "drop" we can speak of water diverted to a use, or water consumed or depleted by the use. A basic question is how much productivity was gained per unit of water depleted from a basin, where depletion includes evaporation and flows to sinks. On the "crop", or production side – the numerator of the water productivity equation - we can speak of physical mass of production such as the amount of kilograms produced. Alternatively, productivity can be related to the value of water. Using valuation, the concept of water productivity can be generalized to cover various uses of water within a river basin.

As a first step to address this challenge, IWMI developed a water accounting procedure that enables identification of opportunities for improving water productivity in a river basin. This procedure also allows us to classify basins as open, closing, or closed, depending on the degree

to which there is utilizable outflow from the basin. The next step is to value the water used for different purposes. Research on this issue is on-going with an interdisciplinary team working closely to value the water used for non-agricultural purposes such as drinking, industries, fisheries, forest, and environment.

IWMI also uses techniques such as Satellite Remote Sensing (SRS) and Geographical Information Systems (GIS) to overcome problems related to the non-availability and unreliability of data, especially irrigated areas under different crops and their consumptive use (see next section).

Hence, there remains considerable scope not only for collecting, analyzing and providing performance-related information, but also for developing and disseminating practical tools for improved management of basin-wide water resources.

Program Focus

The Irrigation and Water Resource Program was formed in 1999, incorporating over most of the activities of the Institute's former research program on Performance and Impact Assessment and some from the former program on Design and Operations of Irrigation Systems[2]. The new program is driven by the following principles:

- Need to develop and apply innovative and integrated approaches for managing increasingly scarce water resources: *e.g., irrigation in the context of water basins, smallholder water management systems.*
- Need to understand the status of water use in basins and countries, and to identify ways to improve the productivity of water in basins: *e.g., water accounting procedures.*
- Need for methodologies to assess performance and to understand reasons for success or failure of designs, management practices and interventions: *e.g., performance indicators, determinants of performance.*
- Need to document impacts of interventions: *e.g., ex-post analyses.*

Work within the program is conducted at three levels, system, basin and global. In particular, it aims to:

- contribute to improving irrigation ***system*** performance by:
  - developing and applying performance measures, and
  - promoting affordable and effective technologies and management practices to improve land and water productivity, reduce poverty, and promote sustainability..
- study interactions between irrigation and other uses of water within river ***basins*** and promote adoption of performance-oriented approaches in planning & management of water resources;
- acquire, analyze and disseminate information on water resources on a ***global*** scale.

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[2] Activities focussed on information technology, and hydraulic and hydrologic modeling were transferred to the new Applied Information and Modeling Systems program, which also came into existence at the same time, replacing the former Design and Operations research program; see next section.

System Level Achievements

Indicators for Performance Assessment

Performance assessment has been a long-standing interest of IWMI from its early days (Merrey 1997). Throughout its existence, IWMI has been in the forefront of developing and applying methodologies for assessing irrigation performance. With increasing scarcity of water, measuring the productivity of water resources is arguably a more important indicator of irrigated agricultural performance than the productivity of land, especially in situations where water is the most important limiting resource. Unfortunately, researchers tend to develop their own indicators to describe the performance of irrigated agriculture, thereby making it practically impossible to compare performance across systems. In response, IWMI has developed a set of indicators that relates output of irrigated agriculture – crop production -- to inputs of land and water (Molden et al. 1998). These indicators enable comparison of performance among systems, including analysis of temporal and spatial variations within one system as well as among different systems (Sakthivadivel et al. 1999a; see Figure III-1).

IWMI's indicators have been used in various countries, including Sri Lanka, India, Mexico, Nepal, Colombia, and Burkina Faso, for diagnosis, intervention analysis, and as a routine tool for monitoring performance at the project level (Garces-Restrepo and Mora 1997; Kloezen and Garces-Restrepo 1998; Sakthivadivel and Gulati 1997). A database to store and analyze the results of applying and field-testing the indicators in over 50 schemes in 22 countries over various periods of time has been built. A six-fold variation in gross value of output per unit of water consumed by crop evapotranspiration was observed across sites, thus demonstrating the scope to increase productivity of water, or crop per drop, in irrigated agriculture.

Data continue to be collected, and analyses are being undertaken to determine how different types of irrigation systems, climate and other variables affect irrigation system performance. At the 17th ICID Congress held in Granada in September 1999, more than 100 participants drawn from 50 countries took part in a half-day workshop on 'Performance Assessment of Irrigation Systems'. There was keen awareness and interest among participants to discuss, debate and learn more about performance assessment and IWMI's performance indicators, which augurs well for their further adoption.

Guidelines for Performance Assessment

Performance assessment is of course more than just crop per drop in agriculture. It also involves diagnosing problems and assisting irrigation managers in routine operations. IWMI has made significant contributions to the development of concepts and methodologies in this direction. Performance assessment procedures developed by IWMI in Burkina Faso (IWMI 1996) were widely disseminated among irrigation practitioners and policy-makers in the country, and have actually been applied in at least one large-scale irrigation scheme in the country (Dembélé 1999). A publication entitled 'Fostering performance-oriented management in irrigation schemes', based on 4 years of field research conducted by IWMI and national and international partners in Asia, Africa and South America, is almost complete (IWMI forthcoming). This provides guidance on the use of various performance assessment indicators and methodologies, depending on the purpose of assessment, who the assessment is for, and from whose perspective it is carried

************ Insert Figure III-1 – supplied separately*******************

out. IWMI participates in the ICID Working Group on Irrigation and Drainage Performance, and its staff is taking a lead authorship role in preparing ICID 'Guidelines on Irrigation and Drainage Performance.'

Impact Assessment

The use of IWMI's indicators for intervention analysis has already been referred to above. The use of a more rigorous approach for assessing impacts, especially applicable when time-series data is available, was demonstrated by Amerasinghe et al. (1998) and Murray-Rust et al. (1999). In the former paper, time-series intervention analysis was used to assess the impacts of rehabilitation interventions, using a selected set of performance indicators as dependent variables. The latter study focussed on assessing the impacts of institutional interventions on different secondary units, as well as on the system as a whole (see section VI). The methodology used is ideally suited to assess impacts in situations where some of the intervention inputs are non-quantifiable and allows separation of long-term impacts of different kinds of interventions, provided that time-series information of sufficient length both pre- and post-intervention exists.

Design and Operations

In performance assessment, it is natural to think of outputs such as yield, income, or crop or jobs per drop of water. It is also useful to think about the irrigation designs and processes that lead to these outputs. IWMI continues to contribute to understanding these concepts and their interactions. An on-going debate in the field of irrigation design and operations concerns the need for flexibility versus the need for simplicity (Plusquellec, Burt and Wolter 1994). Should the drive for increased performance result in increasingly complex designs that generally afford operators more flexibility? Or are there alternative approaches? How is one to ensure that management, organizational and institutional aspects are also taken into consideration in irrigation design, and not only the usual technical criteria? IWMI published a book with Wageningen Agricultural University (Horst 1998) addressing just such issues. The book presents arguments for simplicity in design to make the task of operations easier, and also provides guidance on the design of irrigation systems oriented to human and management factors.

A series of studies to analyze the sensitivity of performance of various canal structures to variations in the settings of the structures and hydraulic inputs shed further light on this question (Renault and Hemakumara 1999; Renault 1999). The impacts of perturbations could be 'upward' (i.e., effect of flow variations in dependent canals on the discharge diverted from the parent canal) and 'downward' (i.e., effect of upstream water depth variation in the parent canal on the offtake discharge) .The results of these studies underlined the importance of understanding the interactions between design and management of irrigation systems, as greater effort is required to manage structures that exhibit more sensitivity.

One of the difficulties facing almost everybody working in irrigation from researchers to managers is the variability within and across irrigation systems. Because of this variability, it is difficult to develop and apply a single design or operational strategy that works for all situations. To simplify this fairly complex situation, a typology of irrigation systems was developed to aid in irrigation systems operations (Renault and Godaliyadda 1999). Criteria for distinguishing the main characteristics at four conceptual levels, system and structures, networks, water, and

consumer, were proposed. Using these concepts combined with simulation modeling it was shown how operations could be improved in Sri Lanka (Godaliyadda et al. 1999), and how modernization of operations should incorporate these concepts (Renault and Makin 1999).

IWMI has also been working on the application of remote sensing for cost-effective performance assessment of large irrigation schemes. This is discussed further in the next section.

Salinity in Irrigated Agriculture

Salinity is a major threat to the sustainability of irrigated agriculture worldwide. IWMI has contributed to the understanding of the problem and to identifying ways to address this issue. A comprehensive review of the causes of irrigation-induced salinity, particularly in developing countries, was carried out (Kijne et al. 1997) and likely remedial management measures including technical, system-level and policy-level interventions have been identified. These include construction of drainage facilities, improved maintenance of irrigation infrastructure, on-farm watercourse improvements, precision land-leveling, water and power pricing, and incentives for land reclamation. Kijne (1996) and Sakthivadevel et al. (1999b) reviewed previous studies and performed detailed analyses of water and salt balances in Pakistan and Northwest India. Both studies concluded that because of salinity, present water management practices are not sustainable. However, modeling studies carried out at the farm level demonstrated that even using deficit irrigation it is possible through improved on-farm water management to manage waterlogging and salinity (Prathapar and Qureshi 1999).

A major study of salinity in five major arid-zone river basins of the world (Aral Sea, Colorado, Indus, Murray-Darling and Nile) has just been concluded (Smedema forthcoming). It was observed that while all the rivers in these basins showed increasing downstream salinity levels, there were considerable differences in the magnitude of this phenomenon from basin to basin. These differences are broadly attributed to the physical characteristics of the respective basins and how they are managed. Measures to control river salinity are discussed together with the attendant technical, organizational and institutional implications. Specific reference is made to changes in current water use practices. IWMI will continue to perform salt and water balance studies at the basin level, and to understand how basin and irrigation system level management practices can help farmers overcome problems of salinity.

Basin Level Achievements

Development and Application of Water Accounting Procedures

A water accounting framework to measure the use and productivity of water at field, system, and basin level and to assess the value of water in multiple uses has been developed (Molden 1997). The procedure, including the use of a consistent set of definitions, is being applied in collaboration with national partners in large and small basins around the world (e.g., in India, China, South Africa, Pakistan, Sri Lanka, Mexico, Egypt and Turkey). Levels of water scarcity have been identified (closed, closing and open basins) and water productivities of irrigated agriculture have been computed. The methodology has proven to be robust in that it can be applied to many differing situations. For example, multiple uses of irrigated water and their values have been accounted for, and indicators have been defined to give information on the productivity of water in the Kirindi Oya basin in Sri Lanka (Bakker et al. 1999). It was shown

that the irrigation system supplies water not only for the farmers' main fields but also for domestic purposes, home gardens, livestock, trees and other perennial vegetation. Furthermore, water is being transferred out of agriculture to meet the growing demands from other sectors, but often without the consent or compensation of farmers with irrigated land and water rights.

A related water balance study was carried out in the same (Kirindi Oya) basin in 1998 to determine the use of water by agricultural crops and perennial vegetation (Renault, Hemakumara and Molden 1999). The most striking finding of this study was that perennial vegetation consumes more water (55% of total annual evaporation) than crops (28%). This study also noted that about 20% of water flows to the ocean. Based on these and other findings, the Sri Lanka Irrigation Department realized that there is indeed great scope for water savings and has recently tightened its management in cooperation with farmers, achieving positive results.

In contrast, case studies from Bhakra command (in northwest India) and Chishtian sub-division (in Punjab, Pakistan) showed that in both cases, the rate of beneficial utilization of water is already high. The studies concluded that the scope for water conservation in large closed basins such as Bhakra and Chishtian is limited because already, most of the water is consumed for crop production. Efforts should therefore concentrate on improving the productivity of the depleted water (Molden, Sakthivadivel and Habib 1999; see Table III-1). The beneficial utilization figures indicate that at Bhakra and Chistian there is little scope for water savings. The water productivity, both in terms of available water and per unit evapotranspiration, shows that at Chistian there is apparently scope for improving water productivity per unit of water, even though there is little scope for saving water.

Table III-1. Water use and productivity in Bhakra and Chistian

General			
System Name	Definition (unit)	Bhakra	Chistian
Command area	(ha)	1,503,000	70,590
Cropping intensity	(%)	196%	147%
Water Use indicators			
Beneficial Utilization	Beneficial Depletion/ Available water (fraction)	0.86	0.89
Productivity indicators			
Land Productivity	SGVP/unit command area (US$/ha)	1,428	586
Water Productivity per available water for irrigation	SGVP/Available water for irrigation (US$/m3)	0.15	0.06
Water Productivity per process consumption	SGVP/Eta (US$/m3)	0.17	0.07

SGVP = Standardized gross value of production.

Work has also been initiated in respect of valuing the water used for different purposes; the results of a recently concluded study at Kirindi Oya, Sri Lanka that computed the values of water for fisheries and agriculture is being reviewed for publication (Renwick et al. forthcoming).

Revisiting Traditional Concepts of Efficiency and Water Savings

By properly accounting for water flows in a river basin, pertinent insights into productivity and water savings, and concepts of efficiency can be derived. Traditional concepts of irrigation efficiency have been challenged (Seckler 1996; Keller et al. 1996; Perry 1996; 1999)[3]. Irrigation efficiency typically relates the volume of water beneficially used (i.e., crop evaporation) to the amount of water diverted to a use. Two major problems have been noted. First, increases in efficiency at a local level often do not lead to water savings at a basin level. Second, increases in efficiency defined in this manner are not necessarily better. For example, higher evaporation with the same diversion may lead to environmental degradation, or water may be evaporated by a less beneficial use than it could have been. The concept of beneficial utilization of available water, or basin efficiency derived by Molden and Sakthivadivel (1999) relates the amount of water depleted by various uses as evaporation or flows to sinks that is deemed beneficial, to the amount of water available for use in that basin. This gives us a physical indication of the scope for additional beneficial use, and an indication of how well water is being used. It does not tell us how beneficial each use is, hence the need for an indicator of economic productivity or value of water.

Related to this, conventional ideas of water savings have been challenged. If we could save water in irrigation, these savings could be transferred to another more desirable use such as more irrigation, domestic, industrial, or environmental use. Such transferable savings of water are known as “real” water savings. Unfortunately, saving water at the field level does not always lead to this type of savings. If return flows from irrigation can be reused, this reuse water cannot be counted as saved. In many river basins throughout the world, the fraction of water supply depleted by evaporation and flows to sinks is very high because of reuse, and there is little scope for saving water[4]. Water accounting as presented by Molden and Sakthivadivel provides a generic means to identify ways to save water and increase its productivity (see Figure III-2).

An on-going project in China in collaboration with the International Rice Research Institute (IRRI) and Wuhan University of Hydraulics and Electrical Engineering (WUHEE) aims to understand how on-farm water management practices of alternating wet and dry irrigation lead to water savings at a larger sub-basin scale (see also Section VII). The concept of ‘hydronomic zones’ (Molden, Sakthivadivel and Keller, 1999) was developed as a simple means to locate places where increases in local efficiency do indeed lead to real water savings. On-going research is being carried out to apply this procedure to a variety of situations.

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[3] This has become increasingly accepted, although it is difficult to attribute this acceptance entirely to IWMI. It is also interesting that even though these concepts seem obvious to us, we still debate this at length with water professionals.

[4] At the September 1999 ICID Congress in Spain, a task force that included an IWMI staff member was formed to study the issue of “basin efficiency”. In the first meeting it was noted that the scope for water savings was quite limited in many major basins including the Yellow, the Indus, the Ganges during winter, and the Colorado. Further work will be done to quantify this situation.

Figure III-2.
*********** include water productivity improvements finger diagram (1 page) *************
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Cascade Tank Systems

A methodology for planning interventions in cascades of small reservoirs (tanks) was developed and applied to the watersheds of Sri Lanka's dry zone (Sakthivadivel, Fernando and Brewer 1997; Jinapala, Brewer and Sakthivadivel 1996; Sakthivadivel and Brewer 1999). This methodology enables planners to use local knowledge to generate hydrological data in a highly efficient manner where few hydrologic monitoring data exist. Both hydrological and socio-economic data are integrated in the evaluation and prioritization of water development proposals through a participatory process with the water users. This methodology has now been adopted in two major donor-funded projects in the North Central Province of Sri Lanka (IFAD, which supported the original work, and World Food Programme), and has significantly increased the effectiveness of government investments to reduce poverty through improved productivity of water. Recently, an NGO in Tamilnadu, India, called 'DHAN Foundation", has also adopted this methodology on a 58-tank cascade. DHAN is also publishing a journal called "Tank Cascades" to popularize the methodology and its application in various agro-ecological settings.

Global Level Achievements

Global Water Supply and Demand

Water supply and demand projections over the 1990-2025 period for about 120 countries were done using a new methodology that enables identification of the nature and extent of water scarcity (Seckler et al. 1998). This approach differs from most food projection studies in that it directly incorporates estimates of water use. According to this study, around one-third of the world's population in 2025 (around 2.7 billion people) are expected to experience 'absolute water scarcity' at that time, even with substantial increases in the productivity of water use. Available water resources will not be sufficient even to maintain 1990 levels of per capita food production from irrigated agriculture, while meeting water requirements for domestic, industrial and environmental purposes. The implication for such countries is that water will have to be diverted from agriculture to other sectors, resulting in reduction in domestic food production and increasing food imports. Another group of countries – involving about 400 million people – will face 'economic water scarcity'; although they possess adequate water resources, massive investments in water resource development will be required to meet their water demands.

Recognizing that aggregate country-level information masks significant regional variations, this study has also been extended to specifically look at in-country spatial and seasonal variability. The analysis of Sri Lanka conducted by Amerasinghe, Mutuwatte and Sakthivadivel (1999) clearly brought to light the fact that at least 5 districts already experience absolute water scarcity, either seasonal or year-round, although national-level statistics indicate no serious present or future water scarcity. More districts are expected to enter this category in 2025 and this situation could have a serious impact on the country's future food production. However, it is shown that if the irrigation sector efficiency in 2025 is double the current level, the resultant water savings in the agriculture sector will be more than adequate to meet future additional demands of other sectors. But the big unanswered question, with major implications for the country's food and development policies, is whether the country has the financial and institutional capacity to actually attain the high irrigation efficiency scenario.

World Water Vision 2025

In continuing the above work on water supply and demand, IWMI has made important contributions to the development of the World Water Vision 2025 to be discussed at the Second World Water Forum in the Hague in March 2000. In collaboration with its partners (the International Food and Policy Research Institute [IFPRI], Stockholm Environment Institute, and others), IWMI has specific responsibility for the Water for Food and Rural Development component. An interactive policy-dialogue model, PODIUM, was developed for this purpose. It estimates future food needs and water requirements, both globally and country-wise, taking into consideration various scenarios of population, diet, climate, yields, trade, and water use in irrigation, industrial and domestic sectors. PODIUM has been particularly useful at country level to facilitate discussion during the Vision exercises. IWMI staff have made approximately 30 presentations of PODIUM at various meetings. On a global scale, results show that even assuming reasonably good increases in the productivity of water and in basin consumptive use, there will still be a need to develop more water by 2025 to serve irrigation, domestic, industrial, and environmental needs.

There are alternative scenarios that could take place. On a pessimistic side, if we cannot build the storage required to develop more water and if water continues to be poorly managed in many areas worldwide, and trade does not increase greatly, average nutritional levels may actually decline from the present. On the optimistic side, there are opportunities to improve the productivity of land and water resources. Indeed, by greatly improving the productivity of water in agriculture, it maybe possible to overcome the need for much additional storage, and the strains of water scarcity will be lessened. This is a tremendous task but this alone justifies the relevance of IWMI's research.

Directions for Future Research

There is scope for increasing productivity of water in many cases through better water management. Therefore, one important exercise will be to find the key determinants of productivity, and to understand better how water management efforts can make a difference. This will allow us to provide good scientific information on targeted interventions.

Our views on performance of water resource use have been at a bulk or aggregated level. We need to disaggregate further, and find out how productivity can be increased in a manner that best serves poor people and disadvantaged groups. Better serving this group of people may indeed hold the key to improved productivity in an aggregate sense.

We will continue to study the interaction of irrigation with other uses, including the environment. This will involve improvements in techniques of valuation, measurements of who uses water, and modeling various scenarios.

Smallholder water management systems, including water harvesting and supplemental irrigation in dry areas, are a new thrust for IWMI. There is possibly large potential to improve water resource use outside of large irrigation command areas. Right now, we do not know the global potential for these systems, but in the near future we should get a better idea.

How groundwater is managed will be vital for sustainability and productivity. On one hand, groundwater is being heavily depleted in many areas. We need to address this problem, understanding better how it happens and its occurrence, and develop strategies to remedy the situation. On the other hand, there is great potential to use groundwater as storage that is untapped. This relies on groundwater recharge – how do we get more water into aquifers so we can use it later?

IV
Applied Information and Modeling Program

Introduction

With the broadening of IWMI's research to include integrated water resources management in a basin context, the Institute has increasingly turned to new technologies to support this expanded mandate. In 1999 IWMI's Governing Board identified information technology (IT) as being of equivalent importance to water resources management as genetic engineering is to the plant sciences. It was partly this recognition that prompted the recommendation to restructure the research programs in 1999. As part of this exercise, IT and modeling activities were brought under the Applied Information and Modeling Systems (AIMS) program.

The mandate of the AIMS program is to conduct basic and adaptive research, with special reference to applying information and advanced modeling techniques to improve irrigation and water management. The program also actively seeks opportunities to apply the tools and techniques developed by IWMI with partners in NARS and implementing agencies, such as irrigation and water resource management agencies. Another important task for the AIMS program is to provide support to IWMI's other research programs in the application of information and modeling techniques.

The AIMS program's current focus is in three broad areas of activity:

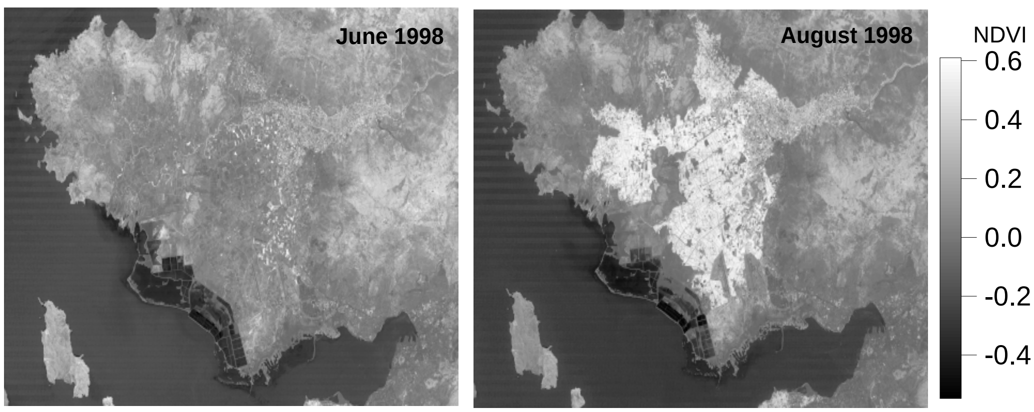
- Advanced information technologies and remote sensing
- Modeling systems
- Statistical techniques and data management.

The first EPMR (TAC 1994) was critical of the relatively restricted use of information technologies at that time. In the intervening period the use of IT and more advanced modeling and analysis techniques has expanded rapidly.

Advanced Information Technologies and Remote Sensing

Over the past 30 years satellite remote sensing has offered new opportunities to researchers and practitioners in many fields related to natural resource management. However, although the potential for applications in hydrology and water management is immense, the uptake of the technology beyond research studies has been disappointing. With new satellite systems becoming available and a decreasing trend in the cost of raw data, IWMI believes that there will be greater opportunities to bring these techniques to managers of water resource systems, thereby enabling significant improvements in resources management. Moreover, reduced national investments in basic meteorological and hydrological data collection in many countries results in fewer observation points and increasing delays between observations being made and data becoming available for use. IWMI's work related to Information technology (IT) and Remote Sensing broadly covers the following three areas: (a) irrigation system performance assessment, (b) basin scale studies, and (c) evapotranspiration estimates.

IWMI's use of remote sensing commenced only recently[5] and started with the irrigation system performance assessment. Since 1996 IWMI has been collaborating with international and national partners in a number of countries to investigate new applications of remote sensing. Advances have been made in irrigation system performance assessment for large irrigation systems, such as those in India, Pakistan, Egypt, and Turkey (Thiruvengadachari and Sakthivadivel 1997; Bastiaanssen et al. 1999a, 1999b; Droogers and Kite 1999). More details of work carried out in this area are reported under the Irrigation and Water Resources program. A measure of the impact of IWMI's and its partners in this field is a recent request to apply techniques developed for mapping evaporative fraction in Pakistan, to the irrigated areas of California.



Using satellite data, information on vegetation density can be obtained for spatial variation in land cover, water use, crop performance, or evapotranspiration. Here an example using Landsat satellite data is applied to a major irrigation scheme in Gediz Basin, Turkey.

Remote sensing techniques combined with Geographical Information Systems (GIS) and hydrological modeling have become powerful performance assessment tools. IWMI, together with national partners in Sri Lanka, India, Pakistan, Turkey and Mexico and an international collaborator (International Institute for Aerospace Survey and Earth Sciences, ITC, Netherlands), has applied these advanced technologies to assess the productivity of land and water, and the effectiveness of water management practices in irrigation systems and river basins. Remote sensing provides objective data that can be aggregated or disaggregated over various scales to provide information that is difficult to obtain by ground studies.

Remote sensing studies have been carried out in India in partnership with the National Remote Sensing Agency of India. These studies have demonstrated that many parameters such as crop yield, evapotranspiration, irrigated area and intensity can be obtained and applied through remote

[5] This has required IWMI to invest quite heavily in hardware and software systems to enable the manipulation and analysis of this type of data. Also IWMI has had to invest in new staff and training for the staff assigned to the tasks. Most RS data sets are too costly for routine use by irrigation and water resources departments, although application of the techniques would often provide highly cost-effective solutions to survey and performance assessment problems. IWMI has emphasized the use of relatively inexpensive sources for remotely sensed data.

sensing, thus providing a way to understand how water resources are being used and to identify areas where improvements are possible. Specifically, the satellite remote sensing study has provided information on the wheat productivity of land and water for a season on the 1.2 million hectare Bhakra irrigation system in Haryana, northwestern India on 30m x 30m pixel basis at a unit cost of US$ 0.03 per hectare. The study has also demonstrated that crop consumptive use of water on a seasonal basis can be estimated using low cost NOAA images and standard climatic data from a meteorological station at a unit cost of US$ 0.01 per hectare. Combining the measures of yields and crop consumptive use gave the productivity of crop evapotranspiration for the whole command area (Bastiaanssen et al. 1999a; Sakthivadivel et al. 1999b). A case study of the Bhadra command area in Karnataka, India demonstrated the use of remote sensing as a tool for measuring the impacts of interventions. It was shown that productivity and irrigated area improved immediately after intervention, but declined again (Sakthivadivel, Thiruvengadachari and Amerasinghe 1999).

The expansion of IWMI's research focus into **basin scale** interactions has resulted in the need for basin-wide data, often available from derived RS data. The basin-scale Semi-distributed Land Use-based Runoff Processes (SLURP) model, adopted by IWMI, makes extensive use of remotely sensed data to provide mapping of surface covers and to infer land use and types. The value of combining remotely sensed data, ground truth and appropriate modeling capabilities was demonstrated in the study of the Gediz Basin in Turkey. The extension of the Gediz Basin modeling into the Kucuk Menderes in just three months was made possible by the use of remotely sensed data and access to public domain data sets. This illustrates that a combined use of RS and public domain data sets can be an efficient mechanism for enabling first approximations of water resources at basin scale (Lacroix, Kite and Droogers 1999).

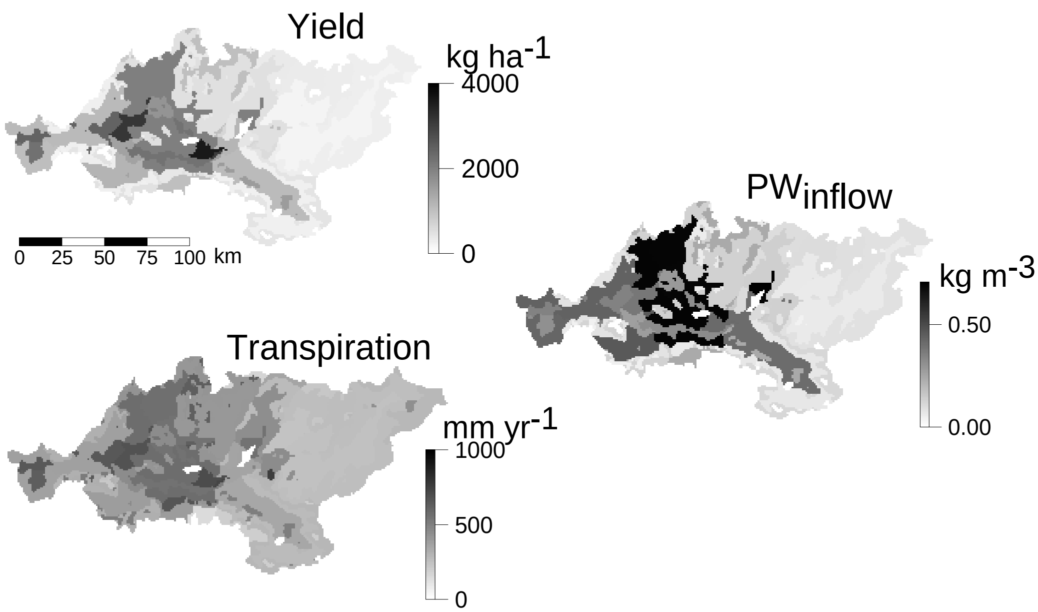
Field-level observations of **evapotranspiration** are reasonable well developed, but there is a clear need for larger-scale estimates, such as at basin level. IMWI has developed and promoted techniques for using IT and RS to obtain these estimates. Four practical applications of the developed techniques are now in the process of being adopted in Sri Lanka (with the Sri Lanka Meteorological Department and the Mahaweli Authority) and Pakistan (Water and Power Development Authority and Indus Basin Irrigation System). With an irrigated area in excess of 15 million ha, Pakistan's Indus Basin Irrigation System is the largest irrigation system managed as a contiguous unit.

In addition to these more practically oriented research projects on evapotranspiration, IWMI took the lead in a more basic research project to compare different methods to estimate evapotranspiration using RS. Field measurements, simulation models and remote sensing techniques were used to estimate evapotranspiration using a common data set. Results and key conclusions were made on the comparison of the estimates and on the applicability of each method. The variation in estimates between the different methods was significant, indicating the difficulty in obtaining accurate values for evapotranspiration. Field methods are labor intensive and give only values for specific sites. Models are able to give estimates in a high spatial and temporal resolution, after a proper validation and/or calibration. Remote sensing techniques are very useful to cover large areas. Several research groups from all over the world contributed to this study and the result will be published in one of the leading journals in hydrology (Kite and Droogers, 1999a).

Future Research

Remotely sensed data are widely recognized as having tremendous potential for application to water resources management. As noted above, the uptake has been slower than this potential suggests should be the case. Some of the slowness may be due to RS technologies not measuring the parameters of direct interest to water resources researchers and managers. In general, empirical regression techniques are used to infer the parameter of interest from the observed data. However, extrapolation of these results to new areas is problematic and hence application of the techniques to new areas often requires more research and empirical studies.

IWMI is not planning to develop an extensive basic research program in the physics associated with remote sensing. There are numerous laboratories that are better placed to undertake this research. However, IWMI is well placed to join in partnerships with these organizations to identify the shortcomings of existing techniques and develop applications to satisfy new needs.



The basin scale model SLURP was used to calculate the productivity of water from yields and transpiration for irrigated, non-irrigated as well as non-agricultural land use, for the Gediz Basin in Turkey

Modeling Systems

IWMI's early use of modeling was in the development and application of decision-support tools in support of irrigation system management. Starting from the hydrodynamic flow simulation model of the Kirindi Oya Right Bank Main Canal in Sri Lanka (Baume et al. 1993), modeling has become an important component of a number of IWMI's research activities. IWMI has developed and applied modeling systems at various scales, extending from individual fields, through irrigation schemes and river basins to national and global policy models. These models include detailed simulations of physical processes in the soil profile, hydrodynamic simulation of canal systems, and advanced hydrological models of river basins. Some examples of IWMI's achievements are discussed at the global, basin, irrigation scheme and field level.

At the **global** scale, the IWMI Policy Dialogue Model, PODIUM, is being used extensively to facilitate national and regional consultations in the formulation of a global vision of Water for Food and Rural Development, in preparation for the 2nd World Water Forum in the Hague during March 2000. The model, discussed above in section III, is recognized as an important tool to generate a range of scenarios that provide a quantitative basis for dialogue and discussion in formulating the Vision (IWMI 1999a; Seckler et al. 1998).

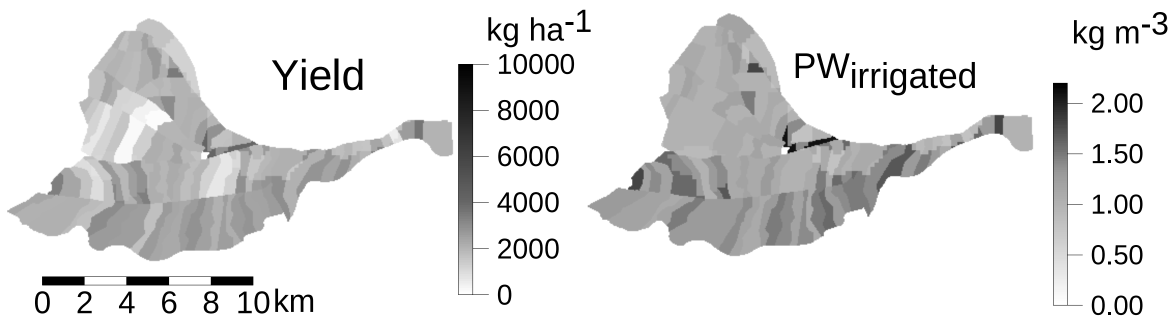
IWMI's use of models has accelerated following the expansion of the Institute's mandate to include irrigation in the **basin** context. IWMI has used the SLURP (Semi-distributed Land Use-based Runoff Processes) hydrological model to simulate alternate management and development scenarios in the Gediz Basin in Turkey (Kite and Droogers; 1999b). The basic model had to be modified to enhance the simulation of irrigated agriculture and was used to investigate alternate basin development scenarios and the impact on agricultural production of changing water allocations to protect the Kus Cenneti wetland area, important as a Ramsar convention bird-habitat (Voogt et al. 1999). SLURP was also applied to the neighboring basin, without modification and without ground based calibration data. The results of this first-approximation simulation proved to be reasonably close to observed data. Simulation of a proposed new reservoir indicated that the yield of the reservoir might have been over-estimated by the reservoir designers (Lacroix, Kite and Droogers 1999).

In Mexico, IWMI scientists have used simulation modeling to investigate water allocation decisions and management alternatives in the Rio Lerma basin. This enabled IWMI to develop new understandings of the management process and to share these with the agencies responsible for the basin. For this specific case in Mexico the clear conclusion of the modeling activity was that the agencies in charge of water management should consider groundwater as a key topic in their management decisions (Scott and Garces-Resterpo 1999).

IWMI and the International Center on Living Aquatic Resources Management (ICLARM) are just initiating joint research on the impacts of the hydrological regime on the fisheries potential of the River Mekong in Cambodia. This will involve application of hydrological modeling using both available data sets and data from public sources. In addition IWMI is assisting IRRI and the Vietnamese Water Resources Research Institute develop research activities in the Red River Basin, Vietnam. At the level of the **irrigation scheme**, detailed analyses on changes in water allocation, cropping patterns, and weather conditions were extensively studied for two irrigation schemes in the Gediz Basin, Turkey. For this work, the field-scale Soil-Water-Atmosphere-Plant (SWAP) model was extended to take into account all the terms of the water balance at irrigation scheme scale. A detailed analysis of a pre-drought and a post-drought period enabled the water managers and researchers to develop a better understanding of and adequate responses to drought events (Droogers et al. 1999).

Following IWMI's use of hydro-dynamic models to evaluate alternate canal and structure designs and operational plans, use of these techniques is now widely accepted in Pakistan. The introduction of these techniques to the agencies in Pakistan is an example of how IWMI fulfils an important role in capacity building to enable the application of tools and techniques in practice (Habib et al. 1999). IWMI is working to combine its hydrologic based modeling work

with economic analysis, for a more complete analysis off water resource management at the basin scale. A team of IWMI and IFPRRI scientists has produced a review of existing hydrologic and economic models that can be applied for various basin level applications (McKinney et al, 1999). IWMI has added an economist to its staff with skills in this area. The review argued that the basin level is the appropriate unit of analysis for most water resource analysis, and that the future direction is to integrate hydrologic, economic, agronomic and institutional models.



A combination of models and field data at the irrigation scheme scale were used to analyze the effect of a severe drought on yields and the productivity of water for an irrigation scheme in Turkey.

One of the lessons that emerged from IWMI's early work on computer-based decision-support tools was the lack of uptake by irrigation agencies. Was this because the models were not targeted towards addressing the real needs of irrigation managers? Or were managers not fully aware of recent developments in irrigation and information technology? This prompted the formation of the Information Technologies for Irrigation Systems (ITIS) network, with the aim of bringing together researchers and practitioners to discuss and promote the application of IT to improve decision-making in irrigation management. Five meetings of the network have been held at more or less yearly intervals[6], each one dealing with a specific theme (e.g., modern techniques for manual operation of irrigation canals in 1997; modernization of irrigation system operations in 1998). A newsletter is also published at a similar frequency. Originally a collaborative effort between IWMI and CEMAGREF, the Land and Water Division of FAO has joined as a co-sponsor in 1998 (ITIS Proceedings – 1998 and also previous years).

Modeling water management within individual **fields** is a new area of research for IWMI. Simulations using the SWAP model have enabled IWMI and its partners in Turkey to gain valuable insights into how irrigation water is managed and used in the field. Such knowledge is now being utilized to "build" the IWMI Virtual Farm. The Virtual Farm will be used to investigate the impact of alternative water management strategies on crop yields (Droogers, Kite and Murray-Rust 1999).

[6] Venues and dates of meetings: Colombo, Sri Lanka (1993); Lahore, Pakistan (1994); Alor Setar, Malaysia (1996); Marrakesh, Morocco (1997); Aurangabad, India (1998).

Future research and development opportunities

New software development tools offer considerable advances in capability to develop professional standard, user-friendly, software. IWMI is fortunate in the location of its headquarters in Sri Lanka. Numerous software development companies have been formed in the country, aimed at supporting commercial software development for markets in the West. We expect to be able to capitalize on the developing pool of experienced professional programmers to support future development of software. These tools make it feasible to take research models and "engineer" them into tools for everyday use. IWMI must be selective in which areas of modeling it chooses to develop and support software tools. Experience tells us that model development is a costly exercise as is engineering, testing and supporting software for wide use. Striking a balance between development of tools required to advance research and development of tools for general use will be an important challenge in the coming years. The IWMI Atlas (see below) and the PODIUM model have expanded international awareness about IWMI and also serve as vehicles to carry messages to a wide, and often new, audience.

AIMS will continue to expand and develop the application of appropriate models for use by IWMI researchers and water resource professionals. In the short term the focus of the modeling group will be to extend the capabilities of the existing range of models to support ongoing or planned research. In addition, the application of newer modeling techniques (Neural Networks, Fuzzy Logic, Genetic Algorithms and Bayesian Belief Networks) to irrigation and water resources management will be investigated.

Statistical Techniques and Data Management

Management of raw data and processing the data to provide useful information is an essential management task. However, the links between data collection and system management are weak in many irrigation and water resources organizations. Much of IWMI's earlier work on Management Information Systems and Decision Support Systems (MIS/DSS) was driven by the need to improve the linkage between data and decision making. Furthermore, statistical analysis of data is an important part of all research programs. AIMS provides advice and assistance on the design of data collection programs and the analysis of field data to other IWMI programs. The tasks related to data management and data analysis are: (a) managing data from IWMI's own research activities, (b) managing global data, and (c) providing support to partners and collaborators.

Management of IWMI data is one element of the AIMS program. IWMI's task of managing data resulting from its own research activities, with some exceptions, has not been adequately addressed in the past. The AIMS program has commenced the development of appropriate data management and data processing tools for the management of IWMI's expanding data archives, most of which are related to IWMI's field research.

At the global level, the *IWMI World Water and Climate Atlas* has been developed by IWMI in collaboration with the University of Utah Climate Center and the Climatic Research Unit of the University of East Anglia. The IWMI Atlas brings together a wide, and growing, collection of public domain data in a common format, accessible in the first place through a purpose-built interface, known as "Synthesizer". Synthesizer makes a broad spectrum of information

accessible to users having no access to Geographic Information Systems (GIS) or the Internet. For users with access to more advanced GIS systems, data layers can be exported from Synthesizer in a standard data interchange format. The IWMI Atlas is a growing collection of a wide range of water, climate and other gridded data products at various temporal and spatial resolutions. Collation of data from a range of sources within the IWMI Synthesizer interface is enabling new analysis methods for use by IWMI and others. The IWMI Atlas is a public domain tool freely available over the internet or on CD-ROM. Since the release of the IWMI Atlas, IWMI has received regular requests for copies of the Synthesizer Compact Disk (CD) and associated data sets. In addition copies of the Synthesizer and basic data are regularly downloaded from the IWMI web site (IWMI 1999b).

Recently, IWMI has used the Synthesizer together with the gridded data from the University of East Anglia to produce monthly Moisture Availability Indices for India and Pakistan. The results show clearly in which areas there is a real need for irrigated agriculture and where there is a need to focus more on drainage topics.

Wherever possible, the tools developed for IMWI's use will be made available to partner irrigation and water resource management organizations through collaborative projects. One example of this transfer of research tools to implementing agencies is the adoption of IWMI's Performance Assessment database system by the Department of Irrigation in Nepal. After slight modification the IWMI database is being used by the Department to monitor and evaluate the performance of irrigation systems following transfer to local management.

Future research and development activities

IWMI, through its global, basin, and system level research is collecting what may be the most comprehensive set of irrigation related data that exists for the world. We are increasing the information on irrigation systems; we have more and more data on specific river basins; through the World Water and Climate Atlas, we have a comprehensive climate database; and through the supply and demand work have assembled an enormous amount of data on global water resources and its use. For these specific activities, we will continue to assemble data and organize it for our own use. We will also publish this data so it can be useful to a larger audience.

More and more public domain data will be applied in water resources management. IWMI now has substantial experience in this, as a provider of public domain data (Synthesizer), as a user (Kucuk Menderes study, Turkey), and as a combined user/provider (PODIUM). IWMI will continue and extend these activities, focussing on the application of these data and the often required transformation from available data towards required data.

IWMI needs to invest time and resources to establish data management protocols and common storage systems to ensure field data can be utilized to the fullest extent possible. Whilst developing IWMI's own data management procedures the AIMS program will seek opportunities to develop data management systems with NARs and Irrigation Departments to ensure compatibility. Where possible IWMI will seek to use existing, commercially supported, database systems and will only develop new systems when other alternatives are unavailable or prohibitively expensive.

V
Health and Environment Program

Background

In 1985, a year after IWMI ("IIMI" in those days) was established, a workshop was organized at headquarters in collaboration with the WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control (PEEM). The follow-up to that workshop took 6 years to materialize and consisted of a joint IIMI/PEEM mission to some South Asian countries in 1991. The mission suggested a research agenda for the Institute, but at the time there was insufficient interest from donors, and the collaborating institutions from the agricultural and irrigation side also could not provide enough support and allocate the required resources.

The First External Program and Management Review (EPMR) (TAC 1994) recommended that the Institute should pay more attention to environmental and human health issues related to irrigation. Specifically, vector borne diseases, agrochemical use in irrigated areas, and downstream environmental impacts of irrigation were mentioned and it was suggested that these be taken up as part of the proposed system wide initiative on water management (SWIM).

In the same year as the EPMR, Danida posted Flemming Konradsen as associate expert to IIMI. He initiated research on health and irrigation with a study on the transmission of malaria and its control through water management in a traditional tank based irrigation ecosystem in the dry zone of Sri Lanka. At the end of 1996 a formal Health and Environment (H&E) Program was established with a mandate for global research on environmental health issues in relation to irrigated agriculture.

Research on water management for the control of vector borne diseases, especially malaria, remained the core activity of the H&E Program and studies have since been done in Sri Lanka, India, Pakistan, and Kenya. The work in Sri Lanka has been particularly productive with more than 10 papers in high-ranking international scientific journals (see for example Amerasinghe et al. 1997; 1999; Konradsen et al. 1997a; 1997b; van der Hoek et al. 1998) and important capacity building components. Several students from collaborating universities have been employed and coached towards postgraduate degrees, IWMI staff have assisted postgraduate courses, appropriate laboratory capacity has been built at the University of Peradeniya, and researchers from IWMI and the University of Peradeniya have just completed a book on "Malaria in Sri Lanka: Current knowledge on transmission and control" (Konradsen et al. forthcoming 2000), specifically aimed at graduate and postgraduate students.

In 1997 case studies were started in Sri Lanka and Pakistan to document the multiple uses of water in irrigated areas as part of the SWIM research agenda. IWMI continues to focus on the uses of water that have specific relevance to human health and the environment, i.e., the domestic uses of irrigation water and the water allocations to aquatic ecosystems (wetlands).

Particularly in Sri Lanka, IWMI had developed successful partnerships with local institutions, largely through the support of students. Considerable effort has gone into establishing

professional networks and the establishment of a database on irrigation and health in Sri Lanka and Pakistan.

Program Goal and Objectives

The overall goal is to contribute to improving the lives of poor people in irrigated areas by optimizing the health benefits of water and minimizing the negative effects of irrigated agriculture on human health and the environment. The program objectives are:

- To improve the understanding of the linkages between irrigated agriculture, the environment, and human health;
- To identify potential health hazards associated with irrigation development;
- To develop water management methods that will improve health or mitigate potential health hazards; and
- To increase the understanding of the non-agricultural uses of irrigation water and how these contribute to human health and environmental sustainability.

Water Management for the Control of Vector Borne Diseases in Sri Lanka

Water Management and Malaria Transmission in South Asia

To assess the feasibility of reducing the transmission of malaria through water management in natural streams and irrigation canals, studies were carried out in a watershed in North Central Sri Lanka from 1994 to 1998. Streambed pools in the main waterway in the study area are the principal breeding sites for *Anopheles culicifacies*, the principal mosquito vector of malaria in South Asia. Throughout the year the abundance of immature *An. culicifacies* was closely correlated with the water levels in the stream. At water levels above 50 cm no immature *An. culicifacies* were found.

Detailed epidemiological studies in one of the villages showed that living close to the stream was a risk factor for malaria early in the transmission season just after the build-up of *An. culicifacies* populations in the stream. Correlations between water levels in the stream, number of immature *An. culicifacies*, adult *An. culicifacies* and human malaria cases could be shown graphically for the entire study period. An irrigation management and water balance study linked with the entomological information identified the most feasible control option: a management routine where water is released from an upstream reservoir during the dry season on a two day basis every tenth day to generate a water level above 60-65 cm in the entire stream. This would dramatically reduce the breeding of *An. culicifacies* in the stream. (Konradsen et al. 1998 ; Matsuno et al. 1999; see Figures V-1 and V-2).

Community based diagnosis and treatment of malaria

As part of the Sri Lankan research a village level diagnosis and treatment center was established in the study area. The reasons for people’s preferences for different types of healthcare facilities and variation of these preferences were documented. After the introduction of the village treatment center by IWMI and its collaborators, it quickly took over the role of main provider for diagnosis and treatment of malaria from the government facilities. (Konradsen et al.

Figure V-1. Water depth and immature mosquito abundance in the Yan Oya stream, Huruluwewa watershed, Sri Lanka. There is a remarkable increase in larval abundance when water levels are low

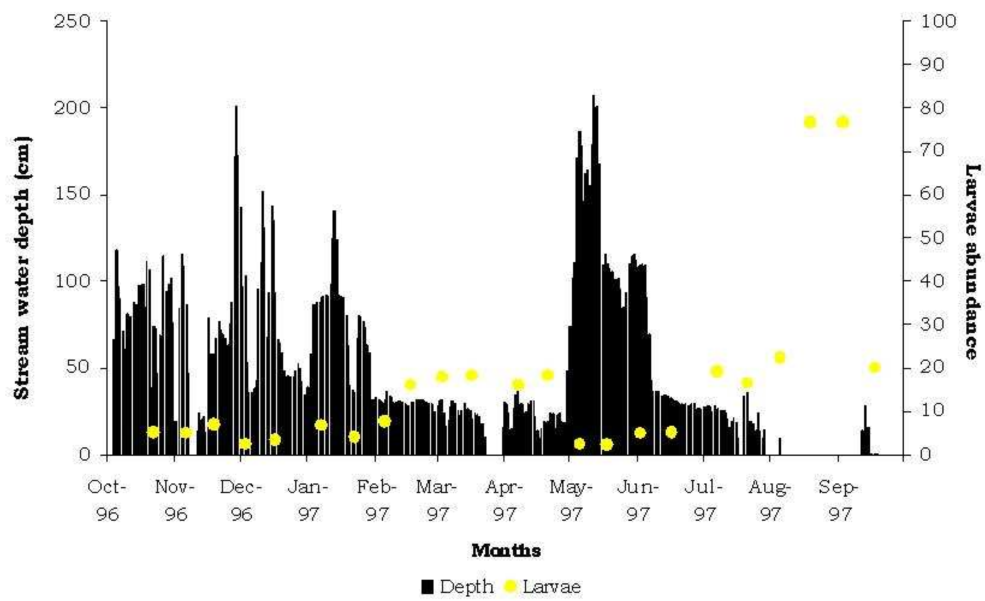
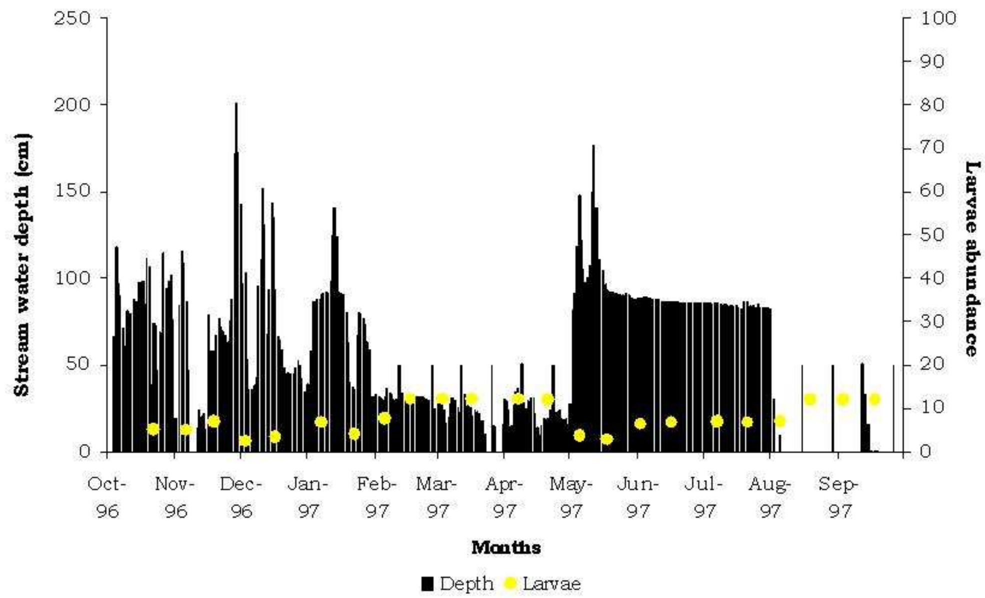


Figure V-2. The scenario when water is issued from the Mahaweli system to the Yan Oya stream in smaller quantities but over a longer period. Larval abundance remains low throughout the year



forthcoming). Early diagnosis and treatment of malaria cases is one of the basic elements of the current global malaria control strategy. The Government of Sri Lanka now plans to replicate this model elsewhere in Northern Sri Lanka.

Cost of malaria control

The cost of different malaria control measures was estimated in a larger study area. Impregnating privately purchased mosquito bed nets with insecticide was estimated to cost US$ 0.87 per individual protected per year, less than half the cost of spraying of houses with residual insecticides. Larviciding of vector breeding sites and especially the above described elimination of breeding habitats by flushing streams through seasonal release of water from upstream reservoirs was estimated to be cheaper than other preventive measures (US$ 0.49 and US$ 0.24 per individual protected respectively). The most cost-effective curative measure for the government is a centrally located hospital with a relatively large catchment area (US$ 1.29 per malaria case treated). Mobile clinics and village level diagnosis and treatment facilities are more expensive options for the government but are considerably cheaper for households than the hospital facilities. The research results can guide health planners and government decision-makers in choosing the most appropriate combination of curative and preventive measures to control malaria. (Konradsen et al. 1999).

Future research

The interventions developed by IWMI and its collaborators over the past few years will be implemented from 2000 in the Huruluwewa watershed in Sri Lanka, in collaboration with water users and irrigation management officials. The results of the studies are also being used to develop a risk map of malaria for Sri Lanka. The risk map will make it possible to target priority areas with control activities and can serve as a decision support tool in health impact assessments for future water resources development projects.

Alternate Wet Dry Irrigation for Water Saving and Vector Control

Alternate wet dry irrigation (AWDI) in rice ecosystems is a promising method to save water, and control malaria and Japanese encephalitis, while maintaining grain yields at the same or even slightly higher levels. Trials are ongoing in India and Kenya and are planned for Sri Lanka and China next year. Preliminary work in Kenya did not yield firm results (Mutero et al. 1999; Van der Hoek et al. forthcoming).

Domestic Uses of Irrigation Water and Irrigation - Water Supply and Sanitation Linkages

Irrigation water is extensively used for non-agricultural, including domestic, purposes. An exclusive focus on water efficiency in agriculture could actually reduce the availability of domestic water within irrigated areas. This was clearly documented in case studies in Sri Lanka and Pakistan in 1997 and 1998. The Sri Lankan study in the Kirindi Oya Irrigation Scheme was the first time that all the uses and users of water have been described in detail in a river basin and a start was made with a framework for valuing the different uses of water. The work was documented in Bakker et al. (1999) and several papers in international scientific journals (Meinzen-Dick and Bakker 1999; Bakker and Matsuno forthcoming); and has been presented at

national and international conferences. It is now widely accepted that water resource policies must take all uses and users into account to avoid negative implications for poor, disadvantaged segments of the population.

The initial case studies have led to two new fields of research: the domestic uses of irrigation water and the environmental uses of irrigation water. In Pakistan, large areas have brackish groundwater, which cannot be used for irrigation or anything else. As a result people depend on canal irrigation water for all their requirements, including drinking water. This domestic use of irrigation water was the subject of baseline studies on disease incidence, water quality, availability of water, sanitation, and hygiene practices. Data collection for the baseline studies was completed in September 1999 and the results will guide in the implementation of intervention studies that aim to improve the drinking water supply and sanitation of people in irrigated areas. Funding is being sought for a partnership that has been established with the UNDP/World Bank Water and Sanitation Program and with the Institute for the Water Environment (VKI, Denmark) to try to bridge the gap between the irrigation and water and sanitation sectors (van der Hoek et al. 1999; Jensen et al. forthcoming).

Wetlands Research

The environmental functions of water and the impact of irrigation on valuable ecosystems emerged as an important issue during the initial case study on multiple uses of water in Sri Lanka. IWMI and its partners are now implementing a baseline study in the Kirindi Oya Irrigation scheme and Bundala National Park to better understand the cause-effect relationship between irrigation and the ecology of a wetland of international importance (a Ramsar site). The baseline study will be followed by the implementation of appropriate water management strategies that could improve and sustain biodiversity. This Sri Lankan study relies on a long-term monitoring program of water flows, water quality, and aquatic vegetation and fauna. In Turkey a different approach was followed in the Gediz basin. The delta of the Gediz river is also a Ramsar site and IWMI staff have used hydraulic models to study the effects of different water management strategies on the wetland ecosystem (Matsuno et al., eds. 1998; de Voogt et al. 1999). The two approaches will be combined in a project proposal to develop a common methodology for studying the irrigation – wetland biodiversity link.

Reducing Risk Factors for Pesticide Poisoning in Irrigated Agriculture

During field visits to irrigation schemes acute pesticide poisoning is often brought up by farmers and health workers as one of their main health problems. A study was conducted consisting of a review of hospital records and in-depth interviews and participant observations in a village. The results of this baseline study, including information on the knowledge, attitudes and practices of the population concerning pesticides has been published (van der Hoek et al. 1998) and presented at scientific meetings. The research showed that hazardous practices when spraying pesticides were due to the impossibility of applying recommended protective measures under local conditions, more than to lack of knowledge. Current programs that promote the safe use of pesticides through education and training of farmers will be ineffective in Sri Lanka because knowledge is already high and because most poisoning cases are intentional. Instead, it was argued that enforcement of legislation to restrict availability of the most hazardous pesticides

would result in an immediate health benefit. In the long term, improved agricultural extension services to promote alternative non-chemical methods of pest control was proposed as the most important strategy to prevent acute pesticide poisoning.

An important impact of IWMI's initial work on pesticide poisoning has been the use of our publication and the adoption of its recommendations by the Presidential Committees on Pesticide Poisoning and on Suicide Prevention in Sri Lanka. In November 1999 a second study will be completed that specifically aims to identify the risk factors for pesticide poisoning and establish whether a shift in agricultural practices towards integrated pest management (IPM) would lead to a reduction in pesticide poisoning. If there are important health and environmental benefits this could be an additional incentive for policy makers to invest in IPM. From next year the focus will be on the potential role of water management in the control of agricultural pests. This is a novel approach but for which there is a biological justification. Trials will show whether the main insect pests in cotton in Pakistan, the American bollworm and the white fly, can be controlled with water management and whether this practice is feasible for farmers to implement. Through measurements of pesticide exposure among cotton pickers using different pest control methods, the potential health benefits of this approach will be assessed.

Future Program Priorities

The Health and Environment Program will focus on five areas of activity in the year 2000 and beyond:

1. Water management for the control of vector borne diseases
2. Domestic uses of irrigation water and the irrigation - water supply and sanitation linkages
3. Irrigation water management and its effects on downstream wetlands
4. Recycling of urban wastewater for use in irrigation
5. Agro-ecosystem management for human health.

Activities 1, 2 and 3 are a continuation of present research activities. Baseline studies have been completed for activities 1 and 2 and emphasis next year will be on intervention studies. Activity 4 is a new field of research for IWMI, in which work was initiated in Mexico in 1999 (Scott, Zarazua and Levine 1999). Activity 5 is an attempt to integrate aspects of activity fields 1, 2, and 3 into one integrated ecosystem approach to human health and the environment at river basin level. This implies that at the river basin level, changes in water management including crop diversification will be evaluated for their effects on vector borne disease transmission, availability of water for domestic use, impacts on downstream wetlands, and also for the need for agrochemical applications. This integrated approach will first be tested in the Uda Walawe basin in Sri Lanka. It should contribute to a river basin management plan in which all the uses of water are balanced in a sustainable way, and may then serve as a model for this integrated approach in other river basins.

The emphasis to date on field based research with original data collection has been important to establish the Program in the international biomedical scientific community. Our extensive data sets have been and will be used by others for example for water balance studies and hydrologic modeling purposes. However, gradually there should now be a shift towards more strategic

research using secondary data or data collected by national partners. This also implies a change in staff composition from the current large number of field staff and small number of international researchers to one that more resembles the situation of the other programs, i.e., a small field staff and a larger international staff cadre.

VI
Policy Institutions and Management Program[7]

"Most of the hard work of crafting new irrigation software [institutions] has yet to be done."
Sandra Postel 1999:253.

Background

From its early days IWMI has strongly emphasized work on institutional and organizational issues. During the first decade, IWMI was known for its work on farmer-managed irrigation systems (FMIS) and water users associations in government irrigation schemes (often referred to as "participatory management of irrigation"). The Institute also carried out studies on government irrigation management agencies (for example in Pakistan and Sri Lanka, and in 1995, in Egypt), financing of irrigation, irrigation investment trends, and the use of participatory means to help countries develop or refine their irrigation policies (Merrey 1997).

By the early to mid-1990s, the largest effort was devoted to irrigation management transfer policies, and the support systems required to sustain locally managed irrigation. In 1994, IWMI co-sponsored a major international workshop in Wuhan, China (Johnson, Vermillion and Sagardoy 1995). Up to 1999 we have continued to study the impacts of irrigation management transfer and the support systems necessary for their success, and to assist countries with testing or strengthening irrigation management transfer policies (e.g., Pakistan, Sri Lanka).

Since 1995, we have broadened our interest in institutional and policy reform to include national and river basin institutional arrangements. We have strengthened the work on poverty and gender; and have worked on the value of water and water pricing. Under new leadership since mid-1999, the Program is beginning to shift the balance of emphasis from institutional studies to include policy studies.

The broad goal of the Program, as reflected in the Medium Term Plans, is to

> identify the necessary tasks, tools, organizational designs and institutional frameworks to achieve and sustain high productivity of irrigated agriculture and improve poor people's lives.

The current concentration on basin level institutions is integrated with work on water accounting described in section III. Work at the community level focuses on gender and poverty as well as supporting systems for local water management organizations.

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[7] In the draft Strategy Paper (IWMI 1999c) we have proposed adjusting the name of the program to "Institutional, Management and Policy."

Policy and Institutional Reforms: Transfer of Management to Users

Local Management of Water and Irrigation Management Transfer

Factors Affecting Transfer Success

The transfer to users of some or all responsibilities and authority for management of previously government-managed irrigation schemes is a major policy objective in dozens of countries around the world. "Irrigation management transfer" (IMT) is the commonly used term for this phenomenon; but the policies vary enormously in their scope, speed of implementation, and extent to which the policy is accompanied by the support required for successful transfer. The Mexico case is famous for its comprehensiveness and speed of implementation, which was made possible by the high level of political support, the lack of alternatives for sustaining the irrigated agriculture sector, and the relatively commercialized nature of the agricultural economy of Mexico. On the other hand, some Asian cases have been slowly implemented, and unlike Mexico, the rules regarding water rights and infrastructure ownership have not been conducive for full farmer takeover of their schemes.

IWMI has published several reviews of international IMT experience to identify the set of essential conditions required for a successful management transfer program. Based on review of existing literature, Vermillion identifies the following conditions as essential:

- a clearly recognized and sustainable water right and water service,
- infrastructure that is compatible with the water service and local management capacities,
- well-specified management functions and assignment of authority,
- effective accountability and incentives for management,
- arrangements for viable and timely conflict resolution, and
- adequate resources that can be mobilized for irrigation management (Vermillion, 1997; see also Perry 1995; Ostrom 1992; Merrey 1996; 1997).

Frederiksen and Vissia (1998), who have considerable experience with implementation, analyze six IMT cases in terms of eight key factors that the authors believe are necessary for successful management transfer. These factors overlap with and complement those discussed by Vermillion and others. For each factor, a set of key tasks is defined. For example, under 'scope of transfer,' the objectives, facilities and services to be transferred, and responsibilities of all parties must be clearly defined. Using these tasks and eight factors, they evaluate and score the six cases (Table VI-1). Two cases, Indonesia and Sri Lanka (discussed further below) score zeros – their programs are rated as inadequate for all factors. Nepal, Mexico, Turkey and USA score relatively higher. Nepal's score may seem surprising, but largely reflects the particular case studied.

A comprehensive study of IMT in India carried in collaboration the Indian Institute of Management Ahmedabad (Brewer et al. 1999; see also section VIII) analyzes state policies and programs and documents key elements in the approaches to IMT taken by the various states. The study shows that although interest in IMT is widespread, the extent to which there has been real transfer is unclear. In most states the transfer policies have remained as statements of intention,

Table VI-1. Rating of the transfer programs

	Sri Lanka	Indonesia	Nepal	Mexico	Turkey	USA
Scope of transfer	Inadequate	Inadequate	Adequate	Adequate	Adequate	Adequate
Condition of facilities	Inadequate (1)	Inadequate (1)	Adequate	Adequate	Adequate	Adequate
Facility ownership	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate (2)	Inadequate (2)
Water rights	Inadequate	Inadequate	Inadequate	Inadequate	None	Adequate
Service Charge, Funding & Finance						
Repayment						
O&M Cost:						
Transport facilities	None (3)	Inadequate	Inadequate	Adequate (4)	Adequate	Adequate
Major facilities	None	Inadequate	Inadequate	Adequate	Adequate	Adequate
Capital cost:						
Rehabilitation (T. F.)	None (3)	Inadequate	Inadequate	None	Adequate	Adequate
Major Facilities	None	None	None	None	Inadequate	Adequate
Finance availability	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate	Adequate
WSE legality	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate	Adequate
Preparation for and execution of transfer	Inadequate	Inadequate	Adequate	Adequate	Adequate	Adequate
Follow-up and support	Inadequate	Inadequate	Adequate	Inadequate	Adequate	Adequate
Number of "adequate" ratings	0	0	4	5	7	11

Source: Frederiksen and Vissia (1998: Table 3).

Notes:

1. Rehabilitation of facilities was incorporated into the management transfer program.
2. Although the ownership of facilities remains with the government, the contract between the government and the WSE contains provisions for periodic inspections of facilities, and if the WSE does not maintain the facilities, the government has the right to do the work and charge the WSE for the cost.
3. By mid-1998, the government and the World Bank were in negotiations for a loan to rehabilitate the distributary systems of parts of the Mahaweli Project. Under conditions of the loan the WSEs will be required to pay 100 percent of the O&M costs of transferred facilities and 10 percent of the capital costs of rehabilitation.
4. Groundwater users do not pay any water service fees, even though their supply is directly attributable to recharge from the surface water that is delivered through the transferred facilities. If these beneficiaries were required to pay for the service they receive, the repayment of O&M costs would improve (presently fees cover about 85 percent of O&M costs).

except for the implementation of some pilot projects. Most of the WUAs exist only on paper. As the major focus of the study was on understanding the transfer process, only quantitative assessments of impacts were done. The evidence suggests that there has been an improvement in the quality of the irrigation service in locations where WUAs have taken over operation and maintenance responsibilities. There is also evidence of farmers shifting to high value cash crops with improved water supply. Some improvements in crop yield have been reported. The governments continue to provide management subsidies and repair and maintenance grants to the WUAs. The study acknowledges the need for more systematic quantitative assessment of the benefits of IMT, but concludes by arguing that IMT is a potential means to improve performance of irrigation systems in India. There is a need to make agencies more accountable to farmers and also induce users to bear a greater portion of the cost of supplying water. Management transfer is an effective means to achieve these two objectives.

The Mexican case is generally considered one of the most ambitious and successful reform programs in the world in terms of the area affected and the speed of its implementation. IWMI studies of the Mexican IMT program clearly show that a strong political commitment and a conducive macro-economic and institutional environment are fundamental to the successful implementation of IMT programs (Johnson 1997; Kloezen, Garces-Restrepo and Johnson 1997). IMT in Mexico has been part of broader macro-economic adjustments and institutional reforms and was accompanied by the introduction of complementary legislation conferring water rights to water user associations and specifying the roles and responsibilities of the users (Kloezen, Garces-Restrepo and Johnson 1997).

A study of the IMT program in Colombia showed that there was only a partial devolution of management functions; the government maintained its control over O&M (Vermillion and Garces-Restrepo 1998). The situation was the same for the IMT program in Sri Lanka (Samad and Vermillion 1999a and 199b) and to a large extent in Indonesia (Vermillion et al. 1999 [forthcoming]) and Nepal.

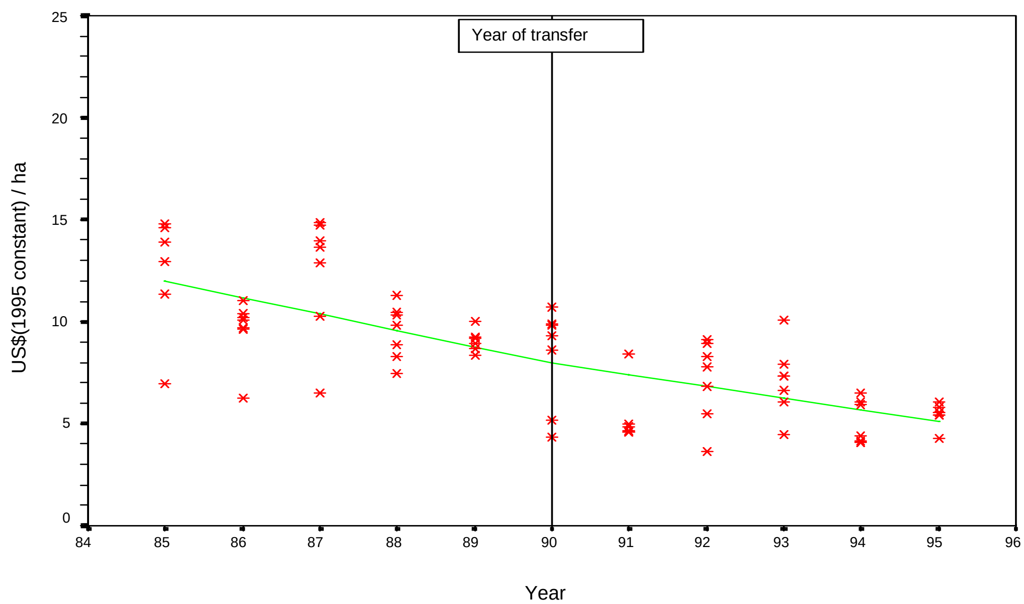
Assessment of Impacts of Irrigation Management Transfer Policies

IWMI's recent research has sought to systematically document the impacts of management transfer on the performance of irrigation and irrigated agriculture. A common methodology was formulated and field-tested in Sri Lanka and then applied to assess IMT programs in Mexico, Colombia, Sri Lanka, Indonesia, India and Nepal.

The case studies verify a significant decline in government recurrent expenditures for irrigation. In Colombia, data from a sample of four districts showed that government expenditure fell from a range of US$ 20-80 per hectare before transfer to almost zero after transfer. In Sri Lanka significant declines in government investments were observed in all irrigation schemes irrespective of whether they were transferred or not (Samad and Vermillion 1999a) – that is to say, there is no direct relationship between IMT and reductions in government expenditures (Figure VI-1). A similar trend has been noted in Nepal (IWMI/Dept. of Irrigation Nepal 1999).

The Sri Lankan study compares the trend in agricultural performance over a 10-year period in schemes that had been transferred and rehabilitated to those with only the effects of management

Figure VI-1. Trend in Government Expenditure for O&M in Transferred schemes in Sri Lanka



transfer, only rehabilitation, and schemes with neither of these two intervention. The results show that there has been a statistically significant improvement in rice **yield** in the schemes that have undergone both management transfer and rehabilitation. There is no statistically significant change in yield trends in schemes with only one type of intervention, and those with no intervention show a significant decline in yield (see figures VI-2a-VI-2d). These findings are consistent with another study carried out by IWMI of the Gal Oya Project in Sri Lanka which showed that there was a significant improvement in performance when physical improvement is followed with institutional interventions (Amerasinghe, Sakthivadivel and Murray-Rust 1998; Murray-Rust, Sakthivadivel and Amerasinghe 1999; see Section III where the methodology used is discussed).

FAO and IWMI have just published a 'Guidelines for IMT' which is partly based on the past decade of IWMI's research (FAO and IWMI 1999). We are also planning a paper that synthesizes and compares the results of the impact studies, to be published in 2000. It is clear that countries should not expect quick or dramatic changes in the performance of irrigated agriculture to result from management transfer alone; and to achieve long term sustainable success requires getting the full set of supporting policies and institutions in place. The modest impacts our studies document may be a function of the short time frame (five years before and after transfer, except the Gal Oya and USA cases). IWMI's work in this area is widely cited, and we continue to receive requests from countries for assistance in formulating, evaluating or testing IMT policies (for example, Central Asia, Pakistan, South Africa, Sri Lanka).

Figure VI-2a. Trend in paddy yield in rehabilitated schemes with IMT

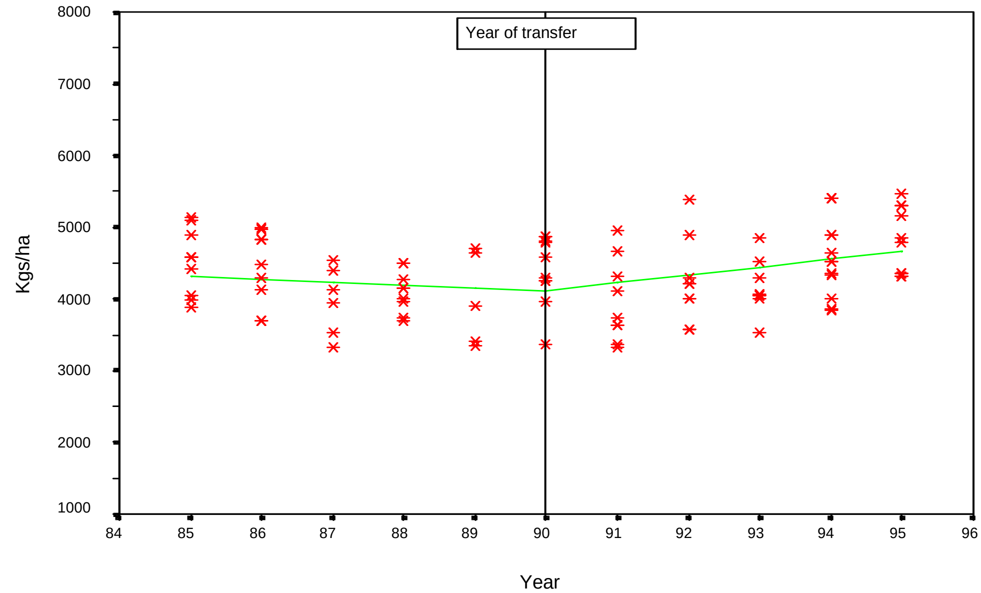


Figure VI-2b.Trend in paddy yield in rehabilitated schemes without IMT

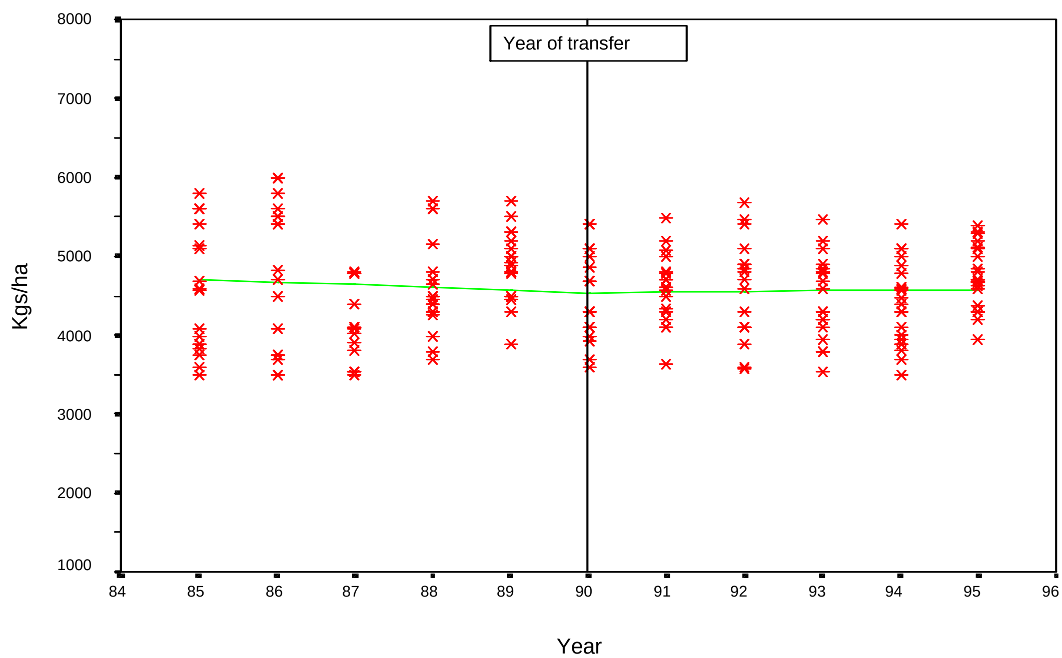


Figure VI-2c. Trend in paddy yield in un-rehabilitated schemes with IMT

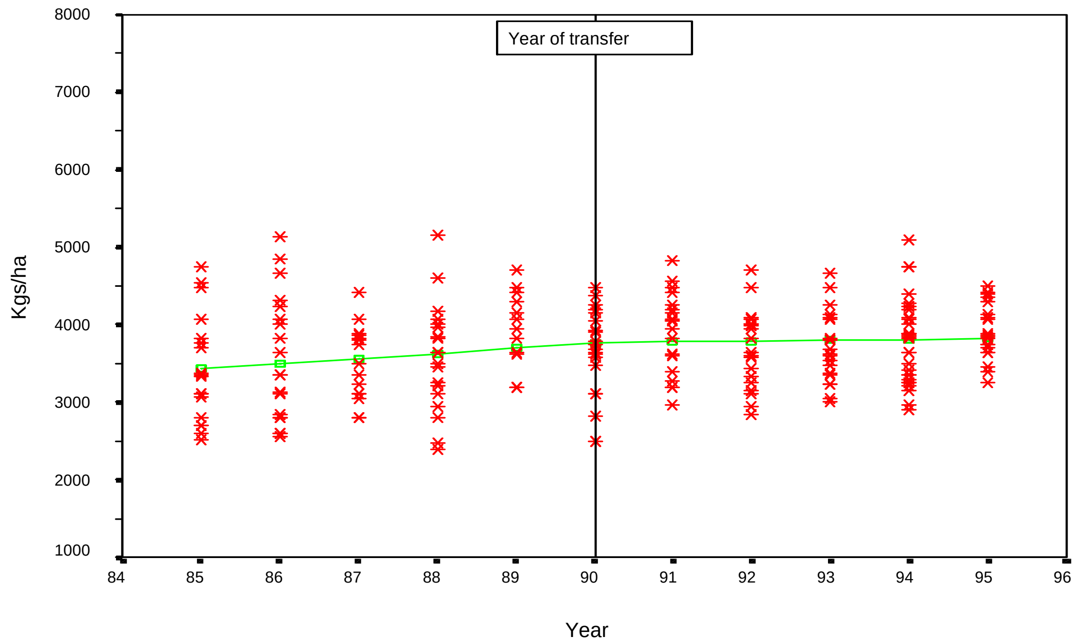
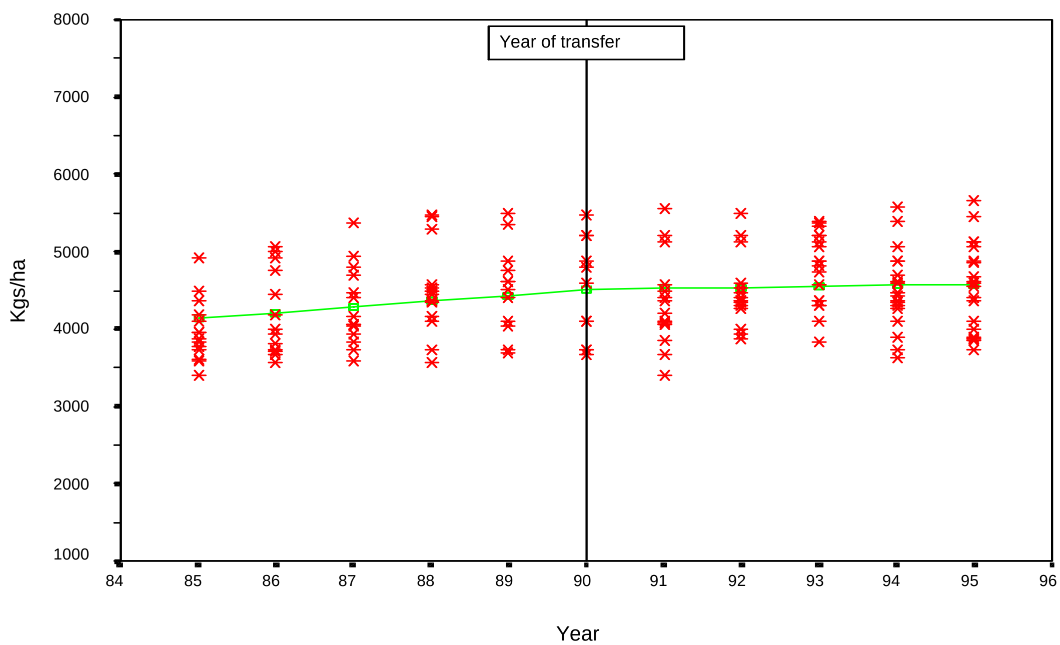


Figure VI-2d. Trend in paddy yield in un-rehabilitated schemes without IMT



Institutional Issues and Reforms in Pakistan

An early IWMI study identified some of the main institutional factors affecting Pakistan's irrigation as follows (Bandaragoda and Firdousi, 1992):

- the overriding effect of socially evolved informal institutions over the formal rules and management decisions;
- the obsolescence of irrigation rules, codes and procedures; and
- the declining relevance of existing organizational structures in the light of changed circumstances.

This work was one of the initial research messages signaling the dysfunctional nature of the institutional framework for irrigated agriculture, and was duly acknowledged in a subsequent evaluation by the World Bank. The common conclusion was that, in order to optimize the benefits of massive investments on both new irrigation developments and rehabilitation efforts, the desired changes needed to be internalized within the social fabric of rural communities. A World Bank (1994) report recommended a set of radical institutional transformations and policy changes intended to reverse the continuing decline in irrigation performance. Despite strong opposition to institutional change by many irrigation professionals, Pakistan's policy makers started to consider the need for change. Several IWMI studies over the past decade have contributed to this policy shift and helped to catalyze concerns and interests on institutional reforms (e.g., Bhutta and Vander Velde 1992; Vander Velde and Murray-Rust 1992; Bandaragoda and Firdousi 1992; Bandaragoda 1998; Bandaragoda and Saeed ur Rehman 1994 and 1998). With this shift in the policy environment, the policy makers with donor support recently initiated important legal reforms and structural changes to replace the traditional irrigation agencies with Provincial Irrigation and Drainage Authorities (semi-autonomous parastatal bodies), and to encourage pilot efforts on organizing water users.

In a study on a sample of 22 watercourses located in 6 different secondary canals in Punjab Province, Bandaragoda and Rehman (1998) found that the actual practice of *warabandi* (fixed rotation) water allocation schedules differed substantially from the design. Not a single watercourse in the study sample followed its official warabandi schedule in daily water distribution operations. Instead, all watercourses with officially sanctioned warabandi had their schedules subsequently modified according to mutual agreement among the water users. All modified warabandi schedules displayed a fair degree of flexibility in terms of time allocation per unit of land, and resulted in yet greater flexibility in their actual application in the field.

Table VI-2 shows that the modifications in the official warabandi have generally resulted in an increase in the irrigation time per unit of land (defined as "time allocation"[8] in this

[8] The "time allocation" is defined, for the purpose of this presentation, as the irrigation time per unit of land on the basis of a constant discharge to the watercourse. The time allocation in the warabandi system is usually understood in hours per acre. It varies from one watercourse to the other, depending on the command area to

presentation). The average value for this measure derived from the official warabandi schedule having 36 water turns is 0.69 hours per hectare. In the modified warabandi schedule, in which the number of turns had increased to 156, the time allocation had increased to 0.83 hours per hectare. This is mainly because some farm plots were not receiving any water at all. The increases in coefficients of variation also suggest that the modified warabandi schedules have resulted in increased inequity.

Table VI-2. Variability of Water Allocation on Hours per Hectare Basis through Warabandi Turns in Watercourse No. Pir Mahal 89-L

Description	Official Warabandi (n=36)	Agreed Warabandi (n=156)
Range	0.42 - 0.93	0.47 - 3.29
Average	0.69	0.83
Standard Deviation	0.09	0.25
Coefficient of Variation	13%	31%

Source: Bandaragoda and Rehman (1998)

Disappointing results from heavy investments on irrigation rehabilitation in developing countries prompted a case study on the Lower Swat canal in Pakistan's North West Frontier Province. The process of planning and designing the Lower Swat Canal remodeling effort conspicuously left out the critically important consideration of the organizational capacity for post-construction system management. Consequently, the changes in physical infrastructure in the re-modeled system did not accompany corresponding institutional changes to support the required operation and maintenance responsibilities. Bandaragoda (1998) draws attention to the institutional implications of current project preparation methods and concludes that the institutional constraints in modernizing old irrigation systems can be foreseen at the planning and design stages. The paper advocates an "institutional impact assessment" procedure that assesses both the impact of infrastructure development design on the existing institutional framework, as well as required institutional improvements, as an essential component of project appraisal for irrigation system modernization in developing countries.

Following up on the concern with Pakistan's stagnant irrigated agriculture performance, the government and donors requested IWMI to undertake action research on how water users can be involved in water management. The general feeling among those promoting reform is that a strategy more likely to help the present situation of stagnant performance is to approach the problem from the demand side of the irrigation management equation, and maximize the role of water users in irrigation management. This involves major

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be irrigated. For equitable distribution, the time allocation measure should not vary too widely among the different farm plots in a given watercourse.

institutional changes from the currently dominant supply-sided bureaucracy. In these proposed changes, the water users would establish appropriate organizations to effectively share the responsibility with line agencies for managing the irrigation systems.

A Pakistani writer, Ahmad Nasir, in his 1992 book on "Decentralization" commented that local government institutions in Pakistan were traditionally dominated by the ruling elites comprising 'feudals' and bureaucrats, who had established monopolies over these institutions and made it difficult for poor and middle class people to share power with them. This comment typifies the common notion about the dysfunctional features of Pakistan's politics and bureaucracy, and the weakness of the country's representative institutions. In this difficult social context, organizing farmers in Pakistan for taking over higher level management responsibilities was described by many as an impossible task.

However, an action research program conducted by IWMI during 1995-1998 at four pilot sites in Punjab and Sind Provinces succeeded in establishing two hundred water users associations (WUAs) at the tertiary (watercourse) level, and four water users federations (WUFs) at the secondary canal (distributary) level (Bandaragoda 1999 [forthcoming]). The organized water users mobilized resources and implemented well-planned maintenance programs, reducing inequity in water distribution along the distributaries. The constraints of an integrated socio-technical system, illiterate farmers, social pressure from big landowners and obstacles caused by the hierarchical society, were overcome through a participatory process of social organization. IWMI's action research has shown that, with adequate opportunity to freely interact among themselves, the water users in the pilot sites are capable of selecting their organizational leaders in a democratic manner to include representation from all sections of the community[9].

These pilot results encouraged the higher political and policy planning levels in Pakistan and the donors to replicate on a wider scale the tested social organization methods. These include a step-wise process of social organization catalyzed by a locally recruited small field team with the assistance of community-based social organization volunteers, training and other forms of capacity building as major motivating influences, and a field implementation coordination committee consisting of representatives of all service delivery agencies working in the area, along with selected water users for farmer-agency coordination. The section on Pakistan in section VIII discusses the impacts of this work.

Institutional Designs for Water Management

An important theme in IWMI's and others' work on farmer-managed irrigation schemes has been to derive organizational principles that can guide us in designing better institutions on irrigation systems built by governments (Coward 1980; Hunt 1989; Ostrom 1992). One reason for the apparent success of farmer-managed systems is they have created mechanisms that ensure a high degree of accountability of leaders to members, and among members. In long-standing farmer-managed systems, the organizational arrangements are congruent with the physical structure of the scheme (i.e.,

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[9] Similar promising results were achieved in an action research program with Pakistani partners on small reservoir systems; but constraints at the policy level combined with a continuing lack of self-confidence of farmers cast doubt on the sustainability of this two-year project (Starkloff et al. 1999).

they are system-specific) and they are autonomous and largely independent of government. On the other hand, in many countries government agencies manage a large number of different irrigation schemes, and are dependent on government for their authority and finances.

Merrey (1996) argues that single irrigation systems managed by autonomous system-specific organizations accountable to the customers perform better and are more sustainable than is the case for systems managed by agencies dependent on government or by agencies responsible for many irrigation schemes (Figure VI-3). The paper compares a number of selected cases and establishes the plausibility of this hypothesis. Although more systematic comparative research would be useful, Merrey suggests the findings are sufficiently persuasive to be used by policy makers interested in reforms. For example, where a government department manages hundreds of irrigation schemes, these should be divested to autonomous user-based organizations.

Perry (1995) discussed the linkages of institutional designs and infrastructure with a particular emphasis on water rights. He argued there are three essential elements for successful irrigation: water rights, infrastructure capable of delivering the service implied by the water right, and assigned operational responsibilities. Where these are properly matched, the system is "functional;" where there is a mismatch they are "dysfunctional." Defining water rights is particularly problematic. He returns to this problem in a recent paper where he notes that water rights are becoming progressively more difficult to define, and more contentious, as water scarcity increases (Perry 1999). The innovative part of this paper is his discussion of how emerging new information technologies can be used to bypass the traditional monopolies on water measurement which currently frustrate the analysis of appropriate allocation among users. The technologies discussed are those described in Section IV on the Applied Information and Modeling Systems Program: use of data sets from the internet, remote sensing, and application of hydrological models to interpret these data.

Policy Reforms: Financing and Water Charges

Water as an Economic Good

The proclamation at the 1992 International Conference on Water and Environment held in Dublin that "water should be treated as economic good" has in recent years emerged as an important policy question. Although support for the idea of treating water as an economic good is widespread, the underlying concepts remain too vague to allow agreement and the precise

Figure VI-3a. Matrix of irrigation system governance arrangements: Performance hypotheses

	RELATIONSHIP OF AGENCY TO GOVERNMENT **Autonomous**	**Dependent**
Agency manages a single irrigation system	1 *Achieve highest performance *Most adaptive to changing conditions *Most sustainable	2 *Mixed but generally low performance *Low adaptability *Sustainability threatened
Agency manages multiple irrigation systems	3 *Performance will vary among systems but overall will be lower than cell 1, higher than cell 4 *Adaptability and sustainability will vary among systems but overall will be lower than cell 1, higher than cell 4	4 *Wide range of, but generally low, performance *Low adaptability and sustainability, with variation among systems based on local factors

Figure VI-3b. Matrix of irrigation system governance arrangements: Examples.

	RELATIONSHIP OF AGENCY TO GOVERNMENT **Autonomous**	**Dependent**
Agency manages a single irrigation system	1 Mendoza, Argentina Irrigation districts, USA, Colombia Taiwan systems Communals, Philippines Farmer-managed irrigation systems, Nepal Irrigation districts, Mexico (post-reform) Self-governing systems, by definition	3 Egypt Haryana, India Punjab & Sind, Pakistan ORMVAs, Morocco
Agency manages multiple irrigation systems	3 National systems under NIA, Philippines	4 Irrigation districts, Mexico (pre-reform) Sri Lanka, Nepal Indonesia technical systems (>500 ha) Most states in India

Source: Merrey (1996).

definition of the implied operational content. A study by Perry, Rock and Seckler (1997) deals with this issue in some detail with a particular focus on irrigated agriculture, the largest consumer of global fresh water supplies.

The study starts from the position that the key question is not whether water is an economic good or not, but whether it is a purely *private* good that can be reasonably left to free market forces, or a *public* good that requires some amount of extra-market management to effectively and efficiently serve social objectives. The answer to this question lies not so much in lofty principles but in value judgements, and their application to different conditions of time and place. The authors argue that water serves many different purposes and has properties that make it both a private and a public good.

In the case of irrigation, the dismal record of the public sector in managing irrigation water supplies has prompted many governments to look for alternative institutional arrangements for water management involving the use of market mechanisms and pricing systems. Privatizing irrigation systems, irrigation management transfer, service-related user charges, volumetric pricing, establishment of water markets and the creation of tradable water rights are some of the measures discussed. The study points out that while judiciously applied market tools can be expected to generate benefits, in many instances the necessary and sufficient conditions are not yet in place to facilitate the effective functioning of markets. It is argued that the flow of water through a basin is complex, providing wide scope for externalities and transaction costs, and also the absence of secure and effective property rights in water could result in market failures. Where markets have worked well, laws assigning rights, describing how rights may be traded, and providing for enforcement of rights and penalties for their infringement, as well as the physical infrastructure and management system capable of allocating water in accordance with water markets, all exist (see Perry 1995). The pursuit of economic approaches in the absence of these enabling conditions may have unpredictable and possibly negative effects.

The study draws attention to the complexity of institutional frameworks required for sound water resource management, especially in developing country contexts when responsibility for the management of water is transferred from a centralized state bureaucracy to local entities and non-governmental organizations. The authors define a necessary and sequential set of preconditions that must be in place for the beneficial introduction of market mechanisms to allocate water. These include:

a) defining the entitlements of all users under all levels of water availability;
b) infrastructure to deliver the defined entitlements;
c) measurement standards that are acceptable to the delivery agency and users;
d) availability of effective recourse to those who do not receive their entitlements and to third parties affected by changes in use;
e) capacity for reallocation of water can be measured and delivered, and third party impacts can be identified
f) policy and legal provisions that obligate users to pay water fees; and

g) large inter- and intra-sectoral water transfers must be subject to approval and relevant charges by regulatory agencies.

These conditions share much with those discussed above as necessary for effective implementation of irrigation management transfer policies.

Approaches to Cost Sharing For Water Services for Agriculture

Charging users for water and water services has been a contentious issue in many developing countries, involving political, social, cultural and historical factors. The combination of these factors is often so powerful that direct charges for the irrigation service are rare. In most instances the full cost of financing the service is borne by government. With increasing budgetary constraints faced by governments there is the high probability of under-funding irrigation resulting in a damage to physical facilities and eventually to the deterioration of the quality of the irrigation service.

In 1995, IWMI carried out studies to assist the government of Egypt to formulate a rational approach to sharing costs among the beneficiaries – agricultural and other users - and government. The studies included an analysis of the impact on the agricultural sector of alternative approaches to cost recovery. IWMI applied IFPRI's model of the Egyptian agricultural sector to evaluate the impacts of three charging mechanisms: a) a fixed rate per hectare independent of crop type or cropping intensity; b) a crop-based charge with higher rates for water-intensive crops; and c) volumetric charges on the basis of actual water use, on farm incomes and crop selection (Perry 1996). The results showed that a standard annual charge set at $52/ha (the estimated cost of the irrigation service) would reduce farm incomes by 4.5 percent but would have no impact on the choice of crops or crop technology. A crop-based charge is as efficient as full volumetric pricing in inducing beneficial shifts in cropping patterns towards more water-efficient crops; farm incomes fell by only 2.4 percent. The benefit from a national perspective was that demand for water fell by 3.5% while returns to water increased by 2.7%.

The analysis also revealed that volumetric charges are an unrealistic means of encouraging significant reductions in demand, because very high charges are required to have a significant impact. To induce a 15 % drop in demand would require a charge that is equivalent to about 25% of the net farm income, hardly a politically feasible option. The study argues that the present delivery system for the most part provides farmers with the water they need – unmeasured and undifferentiated – at the farm level. Any form of rationing or volumetric delivery requires quite a different infrastructure to allow the measurement of individual supplies and differentiation of deliveries between farmers. The benefits from the required investment are small in relation to the likely financial costs of the infrastructure.

Financial viability of irrigator organizations in West Africa

Research on farmer-managed irrigation schemes in Niger and Burkina Faso found that although the irrigation systems produce acceptable results in terms of yield, land utilization and gross output, their organizational arrangements and financial weaknesses pose serious threats to the sustainability of the irrigator organizations. In neither country

are the organizations developing financial independence; they are unable to accumulate reserve funds to cater to future needs for major repairs and renewals and they also face shortage of operational funds. In fact they would be technically bankrupt if they were true private-sector business enterprises because their net available resources are generally negative.

Table VI-3 shows the state of three rice-producing cooperatives' funds at a specific point in time, the end of the wet season of 1996. If the restricted accounts (that is, the funds intended for capital purposes) were really retained, these organizations would all be insolvent. The Kourani-Baria cooperatives are insolvent in any case, and can only make cash payments for vital needs such as electricity and fertilizers after considerable delays. Kourani-Baria II cooperative has not yet been able to put anything into its savings account. The most successful cooperative, Saga, has developed a savings account, but must regularly withdraw funds to meet current cash needs.

The experience of these two countries also suggests that it is desirable to retain some degree of residual government agency involvement in irrigator organizations, such as in helping them to achieve financial transparency. But any such involvement must be clearly defined and circumscribed to avoid situations where the organizations tend to remain permanently accountable to and dependent on government. Most of the maintenance deficiencies observed seem to stem from the organizations' belief that, eventually, the government will come to their rescue and carry out whatever work that has to be done; i.e., it is a moral hazard problem (Abernethy and Sally 1999; Abernethy et al. 1999 [forthcoming]).

Gender, Water and Poverty

Background

IWMI's research on gender issues started in the early 1990s with short-term assignments. In 1993 Margreet Zwarteveen joined IWMI as an Associate Expert. In partnership with national researchers, students, and international institutes, she initiated case studies on women's roles in irrigated agriculture in Nepal, Burkina Faso, Bangladesh, and later in Mexico. The resulting Research Reports and articles in international journal studies are widely cited (Zwarteveen 1995a, 1995b, 1997a, 1997b, Zwarteveen and Neupane 1996, Meinzen-Dick and Zwarteveen 1999). In 1996 she received the ICID Award for Young Professionals for her work.

The EPMR (TAC 1994) advised the Institute to expand this research and ensure its further integration in IWMI's overall program. Following up on this, IWMI hosted an international workshop on 'Women and Water' in 1997, in which leading scientists on gender and land and water resources pulled the available knowledge together and assessed the state of the art in this young academic field (Merrey and Baviskar, eds. 1998). Key papers were also published in a special issue of an international journal (Cleaver, ed. 1998). The workshop was followed by the recruitment of a gender specialist and the establishment of the global Gender Poverty, and Water Project as part of the Policy Institutions and Management Program in 1998. At the same time a country-based

Gender Poverty and Water Program started in Pakistan, and gender research in Latin America continued (Bastidas 1999).

The Gender, Poverty and Water research continues to study women's roles in irrigated agriculture, but it also examines inclusion and exclusion of poor men irrigators and includes policy and intervention analysis**.** The overall research aim is to identify practical policies that can provide both poor women and poor men improved access to water (Van Koppen, 1999a, 1999b, 1999c). We have recently initiated comparative field research in six countries: Pakistan, Nepal, India, Sri Lanka, South Africa, and Mexico.

Table VI-3. Financial position of rice-producing co-operatives at 30 October 1996, Niger

Units : FCFA

	SAGA	KOURANI-BARIA I	KOURANI-BARIA II
Assets			
Bank accounts: Current account	495,552	224,338	87,567
Restricted account	24,856,818	4,278,248	-
Frozen accounts (BDRN)	2,494,590	10,778,053	-
Total	27,846,960	15,280,639	87,567
Debts owed to the co-operative:			
Irrigators' arrears	27,544,009	70,989,955	14,751,365
Others	2,708,868	4,755,698	
Total	30,252,877	75,745,653	14,751,365
Total of assets	***58,099,837***	***91,026,292***	***14,838,932***
Liabilities			
Debts owed by the co-operative to:			
Fertilizer suppliers	3,100,000	52,003,680	-
NIGELEC	597,448	2,613,473	-
ONAHA	1,000,000	496,540	8,197,377
RINI	1,822,690	500,000	-
Centrale d'Approvisionnement	-	-	1,961,500
Ferme Semencière	1,560,125	-	-
Total of debts	***8,080,263***	***55,613,693***	***10,158,877***
Net assets	50,019,574	35,412,599	4,680,055
Net current assets	19,980,975	-46,355,409	-10,071,310
Net current unrestricted assets	-4,875,843	-50,633,657	-10,071,310
Net assets per available hectare	126,312	87,288	18,260
Net current assets per available hectare	50,457	-114,260	-39,295
Net current unrestricted assets per available hectare	-12,313	-124,806	-39,295

Source: Abernethy et al. 1999: Table 10.

Source: System Directors and accountants of the co-operatives

Notes:
1. Net assets = total financial assets - total financial liabilities
2. Net current assets = net assets - frozen accounts - irrigators' arrears
3. Net current unrestricted assets = net current assets - restricted accounts

Capacity Building and Policy Dialogue

In each activity, the research process is deliberately used as an opportunity for capacity building on the concepts and methodologies to address gender and poverty issues in water management**.** In the current research activities, 16 senior and junior research partners, five M.Sc. students, and two Ph.D. students benefit from this on-the-job training. This form of capacity building is complemented by seminars for a wider audience, hosted by the collaborating research institutes (South Africa, India). Dialogue with national policy makers and peers takes place in formal steering and advisory committees (Pakistan, Nepal), regular workshops (Nepal, South Africa, India), and informal meetings (South Africa, Nepal, India, and Pakistan). This discussion of the research questions, methodology, and preliminary findings not only guarantees that policy makers become more familiar with this relatively new issue but also raises their interest in the final findings and policy recommendations.

In South Africa, for example, preliminary field work revealed that the proposed path for irrigation management transfer in a state-managed scheme in the Northern Province would encounter insurmountable problems with regard to land tenure. A much simple form of transfer, namely directly to water users irrespective of land titles, was suggested for policy makers' consideration; they then shelved the earlier proposal. Membership vested in water users also offers more opportunities to women, who are the majority of smallholders in South Africa but tend to have weaker land rights than their male kin (Van Koppen 1999d).

Discussion and dissemination of findings and policy recommendations is organized through national workshops, research papers and audio-visual training material (Video forthcoming). A second International Workshop is planned for January 2000. Global policy makers have also solicited IWMI's expertise. The World Water Vision Unit in Paris recently asked IWMI to assist in mainstreaming gender and poverty issues in the overall World Water Vision, and the sector document on Water for Food and Rural Development in particular. Last September the International Commission on Irrigation and Drainage (ICID) asked for IWMI's assistance to institutionalize attention for gender issues in irrigation and drainage in their organization.

Raising Awareness

A significant change can be observed in the perceived importance of the research agenda. At the start of this decade, merely raising 'women's issues' was met with indifference, if not skepticism, even among IWMI's own staff. By 1997, as measured by the wide citation of its publications worldwide, IWMI's gender research had significantly contributed to a general appreciation of the legitimacy of gender issues in irrigation management. A major achievement in this regard is in Pakistan. In the mid-1990s gender issues still met wide and overt resistance. Three years later, however, IWMI's gender program has attracted the interest of both NGOs and national policy makers.

Today, at the end of the decade, a keen awareness has grown that not only the marginalization of women farmers, but the marginalization of both poor male and female

smallholders is a key concern for the water sector, especially under future growing water scarcity. This issue is an important theme in IWMI's overall agenda. Coordinated and multi-disciplinary efforts are devoted to the challenge to develop pro-poor and gender-inclusive irrigation and water resources policies that contribute effectively and efficiently to the wellbeing of poor male and female smallholders.

Research findings

The general pattern that emerges from IWMI's early studies on women's roles in irrigated agriculture, as listed in Table VI-4, is that irrigators are *primarily* women in, first, *de jure* or *de facto* female-headed households (FHH). This type of household may constitute a small proportion of the irrigating households or a large majority, as is the case in South Africa. In most studies local arrangements were found in which women manage rather well to get their water, although in times of scarcity they are reported to have more problems than men. Only in rare cases, such as Ecuador, is irrigation still seen as an exclusively male task even in female-headed households. Second, women in male-headed households (MHH) are also *primarily* irrigators if they manage their own irrigated production units, as in Burkina Faso. Women from both these categories are relatively more interested to participate actively in traditionally male-dominated water users associations if they see an advantage of such participation. The risk of a greater burden of maintenance obligations was a disincentive for women in the Nepal case (Zwarteveen and Neupane 1996).

Table VI-4. Overview of IWMI case studies women's role in irrigated agriculture

	Studied forms of women's irrigated farming	Women's access to water on plot	Women participating in WUAs
Nepal (Zwarteveen and Neupane 1996)	FHHs (minority of all HHs)	good, fewer obligations	no
Bangladesh (Jordans and Zwarteveen 1997)	a. FHHs (minority) b.women in MHHs	a. generally good b. both men and women involved in irrigation	started, supported by agency
Burkina Faso (Zwarteveen 1997a)	women with own plots (minority)	good	sometimes
Ecuador (Bastidas 1999)	a. FHHs b. types of MHHs	a/b men most involved even in FHH	a/b. rare
South Africa (Van Koppen, 1999d)	women majority of irrigators	men hardly involved	both men and women in committees

FHH = female-headed households. MHH = male-headed households.

Women in male-headed households working on their husbands' fields, on the other hand, either irrigate jointly with their husbands, especially among the poor, or they leave this task to the man and only replace him during his absence. This category of women rarely participates in water users associations when their husbands already go. However, active encouragement by intervening agencies stimulates these women to participate as well.

Another important finding is that women who have access to land and other productive assets, make highly productive use of it. This is consistent with the literature, which, moreover, reports that smaller holdings reach a higher land productivity than larger holdings (Van Koppen, 1999a, 1999c).

Ongoing Research and Future Orientations

Pro-poor and gender-inclusive water policies comprise three main areas, both at scheme and basin level. These are new and existing irrigation schemes, and water-scarce basins. The ongoing research is structured accordingly.

New schemes: targeted water development

Central research concern

Targeting technical, institutional, and financial support to the poor and providing new access to water management infrastructure for large numbers of poor women and men smallholders is a major means to improve the agricultural output of very small holdings and to alleviate poverty.

Forthcoming outputs

Policy recommendations will be derived from the ongoing South Asian case studies of public infrastructure development (4 cases), and and private infrastructure development (3 cases).

Future

As part of IWMI's recent emphasis on smallholder water management systems in dry areas, such as supplemental and precision irrigation and rain water harvesting, the focus will shift to the access to and adoption of these particular technologies by both poor women and men in South Asia and Africa.

Existing schemes: equity in water management

Central research concern

In existing schemes poor water users, women water users often have particularly weak water rights, but bear full obligations. Their wellbeing can be improved by redressing these inequities in rights and obligations, for instance, by opening up formal membership in water users associations, first, to water users who use but do not own the land, and, second, to more than one member per household. Specific interventions in existing programs such as irrigation management transfer and rehabilitation often offer ample but largely untapped opportunities to that end.

Forthcoming outputs

Policy recommendations will be derived from the ongoing case studies of irrigation management transfer in Pakistan, India, Sri Lanka, and South Africa.

Future

The emphasis on irrigation management transfer in South Africa and Pakistan will continue. As part of IWMI's overall work on poverty-focused smallholder irrigation in South Asia, the research attention in India and Nepal will shift to collective management and rehabilitation of village tanks and ground water recharge devices. Moreover, we will broaden our focus to include women's and men's benefits from multiple uses of irrigation water.

Water-scarce basins: Pro-poor and gender-inclusive integrated water management

Central research concern

Under growing competition for water there is an immense threat that the needed water savings will be forced upon the poor with weaker water rights, whereas those poor smallholders without access to infrastructure yet, risk being excluded forever. Pro-poor and gender-inclusive integrated water management protects poor people's current water rights, allocates new water rights to poor people who are new irrigators, and ensures that the needed water savings are borne largely by the non-poor.

Forthcoming outputs

A better understanding of these new, highly complex problems, and first policy recommendations for pro-poor and gender-inclusive integrated water management in water-scarce basins will be derived from two ongoing case studies in Nepal and South Africa.

Future

As an integral part of IWMI's overall basin-work, new studies will:

- assess current water use by poor women and men and the impact of increasing competition on this use, and develop monitoring tools to that end
- analyze processes of representation of poor people's interests in river basin management institutions, to identify effective policies for their more effective representation
- assess water productivity according to class and gender.

During the workshop of January 2000 findings from IWMI's ongoing research in South Asia on gendered smallholder irrigation and policy and intervention analysis will be discussed to identify policy implications and remaining gaps. These results will guide further research. In October 2000 a similar exercise will take place in South Africa, in collaboration with the South Africa National Committee for Irrigation Development (SANCID). Research dissemination, capacity building, and policy dialogue will continue as described above.

Conclusion: Future Directions of the Policy Institutions and Management Program

Our work on river basin institutions really began only in 1999, through implementation of two donor-funded projects covering about ten river basins in as many countries. These basins represent a range of hydrological and institutional characteristics. Some are in the midst of major reform processes (e.g., the South Africa and Mexico basins); all are facing severe water scarcity and pollution issues. Some are taking a bottom-up participatory approach to forming basin-level institutional arrangements (e.g., South Africa and Mexico again); others are taking a more centralized approach (e.g., Turkey). The work on these basins combines water accounting and performance assessment with institutional analysis; results are expected beginning in late 2000.

Vermillion and Merrey (1998) draw attention to the requirement for major institutional reforms in most developing countries if they are going to respond effectively to growing water scarcity. The most important reforms are:

a) replacement of administrative with service delivery organizations;
b) conversion of irrigation systems to multiple use water service systems;
c) transcending the infrastructure dependency-deterioration trap; and
d) implementation of integrated water basin management.

Vermillion and Merrey suggest the diversity among water basins requires an experimental approach to encourage the evolution of effective institutions; there is no universal solution. The starting point in IWMI's current work is that there are a limited number of essential tasks that must be done for sustainable and effective management of water basins. These functions are of two types, 'water resources policy and regulation,' and 'water service delivery' functions. For each basin, the questions are:

1. Are the essential tasks being done?
2. If so how effectively are they being done?
3. What are the gaps, and what are the possible solutions to fill these gaps?

An important conclusion of IWMI's work on transfer of irrigation management to irrigator organizations is the critical role of the over-arching policy framework within which these programs are conceived and implemented. This is a key determinant of success or failure of transfer programs. Studying policy frameworks affecting the water sector is becoming important to IWMI for other reasons, too. For one, there is a growing sense that water sector policies are not changing as fast as new problems are emerging; second, policy initiatives that are adopted in developing countries commonly lack a sound analytical basis and therefore prove difficult to implement, when not self-defeating. With the growing recognition of water scarcity as the central challenge facing the world, a need is increasingly felt to work on a larger—and in some ways more potent -- repertoire of instruments of policy action in the water sector.

Newer issues that have come to the center-stage of IWMI’s agenda also make policy analysis important. For instance, IWMI’s concern with poverty and gender issues enjoins it to develop better understanding of small holder water management systems and the role of government policy as it affects these. In many developing countries, groundwater is fast surpassing government-managed canal systems as the primary source of irrigation. In groundwater irrigation, institutional issues are of a totally different genre and can not be analyzed except in conjunction with broader regulatory and policy frameworks at national and sub-national levels. For example in the South Asian region, where groundwater accounts for nearly 60% of all irrigation, groundwater irrigation is farmer-managed; but the central challenge facing it is not so much of cost recovery or even efficiency but equity and sustainability.

In evolving the future agenda of the Institutions, Management and Policy Program, IWMI’s key hypothesis is that, taking the river basin as a unit of analysis, we can develop a better understanding of the complex issues of efficiency, equity and sustainability in water management by expanding our work to encompass institutional as well as policy analyses. The broadening of the focus will be accomplished gradually over a year or so and will be integrated into IWMI’s current work on institutional support systems for sustainable water management.

VII
System Wide Initiative on Water Management (SWIM) Phase I

Introduction

SWIM (1999) reports on the results of the first phase of the System Wide Initiative on Water Management (SWIM). This initiative was modest in size, and was designed in a way that would lead to follow-up on interesting areas through the normal research programs. The summary given here is based on the phase I report, and indicates what follow up is envisioned on each of the topics. In some cases work is continuing; and at the end of 1999, Phase II of the SWIM work is being initiated.

Accounting for Water Use and Productivity (SWIM papers 1 and 8)

One of the most important tasks for SWIM has been to establish a standard procedure of accounting for water and measuring water productivity. Even among irrigation and water management researchers, there continues to be considerable confusion in the use and interpretation of terms such as "irrigation efficiency" and "water productivity." SWIM Paper 1, *Accounting for Water Use and Productivity* (Molden 1997), sets forth a methodology for accounting for the use of water and measuring water productivity in an irrigation system. SWIM Paper 8, *Multiple Uses of Water in Irrigated Areas* (Bakker et al. 1999), illustrates the application of this methodology at a research site in Sri Lanka. The methodology is now being widely used in other studies at IWMI.

Work will continue in Phase II of SWIM as well as through the Irrigation and Water Resources, Policy Institutions and Management, and Health and Environment Programs.

Increasing the Productivity of Water (SWIM Papers 2, 5, and 7).

Productivity and Prevention of Resource Degradation

One of the major issues facing irrigated agriculture is the continuing loss of crop area and reduction in yields due to salinization. Colleagues at IWMI, the West Africa Rice Development Association (WARDA) and other institutions worked together to review the literature on this subject. Two small workshops were held in the fall of 1997 in Pakistan and in Senegal. The first phase of this work was completed with the publication of SWIM Paper 2: *How to Manage Salinity in Irrigated Lands: A Selective Review with Particular Reference to Irrigation in Developing Countries* (Kijne et al. 1997).

In Phase II, a project on salinity management in West Africa has been prepared by WARDA and IWMI, and may be initiated shortly in collaboration with ORSTOM and CORAF.

Water Efficient Irrigation in Rice-Based Systems

A team of scientists led by IRRI has been studying ways to increase the productivity of water in rice-based systems. An IRRI/IWMI team made field trips to China in May and India in October 1997 and a review of literature was published in 1998 – SWIM Paper 5, *Producing More Rice with Less Water from Irrigated Areas* (Guerra et al. 1998). IWMI and IRRI scientists are now cooperating with Chinese scientists in further research on this topic (see section III).

Managing water scarcity and increasing the productivity of water in the dry regions and water-scarce areas present a major challenge. The International Center for Agricultural Research in Dry Areas (ICARDA), the International Center for Research in Semi-Arid Tropics (ICRISAT) and IWMI conducted a review of literature on farm-level techniques for raising water productivity such as *water harvesting,* and *supplemental irrigation.* A major conclusion of SWIM Paper 7—*Water Harvesting and Supplemental Irrigation for Improved Water Use Efficiency in Dry Areas* (Oweis, Hachum and Kijne 1999)—is that improved techniques of water harvesting have not been widely adopted by farmers because social, economic, and management factors were inadequately integrated into the development of the system and that both techniques provide real opportunity for improved water productivity in the dry areas.

In Phase II, IWMI, ICARDA, ICRISAT, and WARDA will work together to address the problems of the water-scarce areas with a particular focus on sub-Saharan Africa. IWMI also plans work on 'small holder water management systems' in India. In December 1999, ICARDA, IWMI, and NCARTT (National Center for Agricultural Research and Technology Transfer) of Jordan will hold a conference on Water Resources Management, Use and Policy in the Dry Areas.

Managing the Allocation of Water (SWIM Papers 3, 4, 6, and 8).

Intersectoral Water Allocation in River Basins

There is an urgent need to improve the management and allocation of water among competing sectoral demands at the river- basin level to achieve greater efficiency and environmental sustainability. A variety (to the layman an often confusing array) of simulation and optimization models have been used to address policy, operations, and research issues with mixed success. Scientists from the University of Texas, IFPRI, and IWMI have reviewed the evolution of modeling and the current state of the art: SWIM Paper 6, *Modeling Water Resources Management at the Basin Level: Review and Future Directions* (McKinney et al. 1999). The paper emphasizes the potential of coupled economic-hydrologic models and suggests the most appropriate directions for modeling to provide answers to real-world policy questions.

This project has led to a closer collaboration between IFPRI and IWMI in the modeling of water policy issues. Research employing river basin modeling continues at IWMI field sites, for example in Mexico. A major focus at present involving IFPRI is in the development of a model that can be employed at the country level to project supply and demand for food grains, taking into account water constraints.

Multiple Uses of Water at the Local Level

Complementing the work at the river-basin level, a study was launched to identify and value of the multiple uses of irrigation water at the local level and to begin to consider the impact of withdrawing water from agriculture. A team of researchers from IWMI, IFPRI, and the International Center for Women met in July 1997 to develop a research strategy. Because there was so little literature or previous research in this area, the team decided to choose a site for testing out methodology—the Kirindi Oya Irrigation System in southern Sri Lanka. SWIM Paper 8 (Bakker et al. 1999; see section V) presents the results of this initial study presenting to the reader the complexity of issues surrounding both users and uses. Conflicts arise among stakeholders representing a wide variety of needs ranging from daily household water requirements, to crop and livestock requirements, and requirements for fishing and wildlife habitats. Most of these stakeholders have no voice in decisions regarding the allocation of irrigation water.

Stemming from the initial work on water quality at Kirindi Oya, a project was developed in 1997 in collaboration with the Council of Agriculture and the Engineering Research Center of the Republic of China entitled *Multiple Uses and Water Quality*. The funds provided over the past 2 years have allowed the work on water quality to be extended to Pakistan and Mexico.

The Kirindi Oya study also reports on the conflict over the competing uses of water for irrigation and for a wildlife habitat. Water from the irrigation system is draining into the brackish lagoons reducing the concentration of salts and destroying the grounds for the raising of prawns and as a habitat for birds, particularly flamingoes. As a part of Phase II, a study has been prepared and submitted for funding in collaboration with the Sri Lankan Department of Wildlife Conservation (see section V).

Improved Water Utilization in a Watershed Perspective

A team led by ICRAF with support from WARDA and IFPRI met in May 1997 to discuss procedures for reviewing and evaluating watershed management practices in other CGIAR centers and in India. The report (SWIM Paper 9—Ong et al. forthcoming) is still being processed, but of the five Center "watershed" projects examined, it was noted that only one dealt substantively with management of the water resource. This reflects the fact that many centers simply do not have the in-house expertise to deal with this issue.

Two other reports have been published which have generated a great deal of interest: SWIM Paper 3, *Water Resource and Land Use Issues* and SWIM Paper 4, *Improving Water Utilization from a Catchment Perspective* (Calder 1998; Batchelor et al. 1998). In fact, SWIM Paper 3, which challenges some of the conventional wisdom and beliefs (among layman, not forest researchers) regarding the impact of forests on soil and water conservation has had the largest number of downloads on the web among all IWMI publications.

VIII
Outreach and Impact Activities

Introduction

This section provides selected information on work done in some of our partner countries. It is not comprehensive, and there is some overlap with research results reported in previous chapters. Nevertheless, they may give the reader a perspective on the priorities within each of these national programs.

Pakistan

Introduction

IWMI has become an independent and honest advisor for all four provincial irrigation departments and the Water and Power Development Authority in Pakistan. We consider this to be the single most significant achievement by IWMI in Pakistan.

IWMI's achievements in various disciplines are summarized under the following headings:

1. Institutional Reforms in the Irrigation Sector
2. Decision Support for Irrigation Canal Management
3. Water Markets in Irrigated Agriculture of Pakistan
4. Salinity, Drainage and Groundwater Management
5. On-Farm Water Management: Evaluation of Bed and Furrow Irrigation Methods.

Institutional Reforms in the Irrigation Sector

The Indus Basin Irrigation System is of central importance to the economy of Pakistan, which is managed by federal and provincial agencies. It is the largest contiguous irrigation network in the world. It transcends all four provinces of Pakistan and forms a continuous semi arid ecological region. It includes three reservoirs, 19 barrages, 12 inter-link canals and 44 independent canal commands. The annual average water supply through this network is about 180 billion cubic meters and the command area is 16 million hectares.

Unfortunately, the quality of irrigation service has deteriorated over time, and the condition of the infrastructure is deteriorating. Charges levied on farmers for irrigation services are inadequate to meet operation and maintenance expenses, in part because the charges and recovery rates are too low, in part because the irrigation departments are inefficient and over-staffed. As a result, productivity is far below potential, salinity and water-logging are spreading, over-exploitation of fresh aquifers is widespread, and excessive use is being made of poor quality groundwater – to the detriment of the soils and the long-term productivity of the sector.

The Government of Pakistan has recognized this and has made a commitment to reform irrigation management institutions. The search for solutions to the problems outlined has resulted in 1997 in the passage of the Provincial Irrigation and Drainage Authority (PIDA) Acts in the Punjab, Sindh, Baluchistan and Northwest Frontier Province. Under these acts, the present Provincial Irrigation Departments will become Irrigation and Drainage Authorities. Farmers would be organized to take over operation and maintenance of watercourses and distributaries. A new institution – the Area Water Board – will be the intermediary between these two levels, receiving water from the PIDAs and distributing water among the federated organizations of farmers. Farmers will be responsible for levying charges for irrigation and drainage services, with the proceeds divided among the PIDAs, Area Water Boards and farmer organizations to reflect costs at each level.

In parallel with formulation and passage of these new laws, IWMI has organized farmer organizations at secondary level in the Hakra 4R distributary in the Punjab Province, three distributaries in Sind province and in the small dams area of Punjab. Short to near term impacts of these activities are summarized below (see section VI).

Farmer Managed Irrigated Agriculture in Sind

An action research program conducted in three pilot distributaries in the Sindh Province found that organizing water users at the secondary level is socially viable. The methodology used was characterized by a step-wise process, catalyzed by a locally recruited small field team with the assistance of community-based social organization volunteers. Training and other forms of capacity building were the major motivating influences. A field implementation coordination committee consisting of representatives of all service delivery agencies working in the area, along with selected water users, highlighted the needed farmer-agency coordination and greatly facilitated an incentive mechanism through collaborative activities.

The three water user federations negotiated with government irrigation authorities and entered into separate joint management agreements (JMAs) for managing water resources at the distributary level. The JMAs could not be given effect as the government suddenly decided to keep them in abeyance due to a procedural difficulty imposed by the present legal framework. However, the water user federations proceeded to test their capacity by undertaking a planned maintenance program during the canal closure period, and also initiating a maintenance-related infrastructure improvement program. Testing the economic viability of water user federations was not completed, as the JMAs were not operational. Replicability of this social organization program lies in the methodology adopted, deployment of small field teams and the use of local volunteers. Sustainability is enhanced by the phased step-wise organizational development process, which has proved to be a success in consolidating the organized behavior.

Small Dams Project

On the 31 small dams in the Pothwar region of Punjab, irrigation performance has generally remained low. To expedite the process of reform by providing new knowledge and potential models for reform implementation, IWMI with the Water Research Institute of the National Agricultural Research Center of Pakistan and the Small Dams Organization of the Punjab Irrigation and Power Department, carried out an action research program. The program was applied at three pilot-sites for an appraisal of improvement in irrigation system development at small dams in the Punjab through the active involvement of water users organizations (Starkloff et al. 1999).

Hakra 4R Distributary

The Hakra 4-R distributary is the largest pilot experiment (Bandaragoda and Memon, 1997) relating to farmers' participation in South Asia. The impact assessment of farmers' participation along the Hakra 4-R distributary pilot project was done to provide information for reform implementers to improve their strategies and approaches for social organization, planners to clarify their concepts, and researchers to develop effective models and methodologies (Waheed uz Zaman, 1998).

The impact on water availability shows that farmers' demands for water supplies since the formation of the farmer organization have started reaching the PID quickly, and the PID now considers the farmers' demands as part of its distributary operation. The general belief was that farmer organizations would be controlled and monopolized by the 'influentials', leading to enhanced inequity rather than equity. Contrary to this belief, farmer organization office bearers of the Hakra 4-R Distributary took many measures to induce water equity. Impacts that speak for themselves as a result of decisions taken by farmer organization leaders, are to refrain from installing seasonal pipes, to assist the Irrigation Department to correct outlets and to improve water equity at the tail reach.

O&M needs have been translated in terms of management and financial responsibilities, with IWMI's active facilitation. This is also a noteworthy impact of farmers' participation. Undertaking cost-effective and cheaper maintenance is another noticeable impact of farmers' participation. The financial analysis shows that maintenance undertaken by the PID is three times more expensive than by the farmer organization. A clear impact of the maintenance undertaken by farmer organizations is that it is cheaper, efficient and based on needs. Participation of the downstream farmers to repair the initial section of the distributary is also visible evidence of impact.

Another prominent feature of the impact of resource mobilization is the farmer-leaders' indigenous knowledge; they also acted as resources persons to harness organizational skills. For organizational networking, water user organizations undertook a wide range of activities (from irrigation management to the environment) to solve problems inherent to the farming community. The impact was quite visible because these problems were solved by mobilizing organizational links and without the need of the informal payments.

Considerably improved interaction between water user organizations and government agencies is a result of farmer organization interface with government agencies. A 24-

point memorandum of understanding was agreed upon. The ideal impact would have been for responsibilities to be transferred to the farmer organizations. Nevertheless, these interactions have still had a substantial impact because a limited role for the water user federation and PID to manage the distributary has been redefined. The second positive impact associated with these interactions is the increased commitment to participatory reforms observed at higher levels of the Irrigation Department. The third impact, as a result of farmer-agency interface, is that informal payments to agency field staff for additional supplies have reduced significantly.

Conclusions from the three studies

The following conclusions can be drawn from the three studies:

- IWMI demonstrated farmers' ability to organize at the distributary level in three distributaries in Sind, the Hakra 4R distributary in Punjab and areas around small dams. Social and institutional constraints, which hampered an equitable access to water, were identified. Furthermore, despite constraints, the WUOs were inclined to adopt measures for enhanced O&M and command area development initiatives.
- IWMI prepared a model for reform implementation at the distributary level for policy makers, farmers, and donors.
- Farmers mobilized resources from private, non-government, and government sectors for literacy programs, fertilizer investment, household water supply schemes, credit for micro-enterprises and agricultural inputs, agricultural extension services, and medical and veterinary services.

Decision Support for Irrigation canal Management

Chasma Right Bank Canal

The Chashma Right Bank has a discharge capacity of 138 cubic meters per second. The main canal off-takes from the Chashma Barrage on the Indus Basin. The 258 kilometer-long main canal serves 230,675 hectares of land in two provinces, the Punjab and NWFP. An intensive distribution system has been provided on the left bank of the canal to serve the command area between the canal and the river Indus. WAPDA requested IWMI to model the hydraulic behavior of the main canal.

IWMI identified:

- low and varying velocity, dead storage, over-drawing capacity of the head regulators, high command areas with lower water demands as the critical parameters affecting performance of the canal.
- sensitive reaches, cross regulators and distributary head regulators, which could face problems during the water stress periods.
- the scope for improvement for about eight problematic distributary head regulators (Habib et al. 1999).

Impact of interventions at primary and secondary canals on water deliveries to tertiaries

At Fordwah main canal in Punjab, current operational rules have induced an inequitable and unreliable water distribution for the water users. IWMI's mathematical modeling study showed that restoration of the official rules is not a solution. The study also showed that it is possible to improve the water distribution at the main canal level, by adopting alternative operational rules. Implementing a rotation throughout the season, involving mainly the larger secondary canals, while maintaining fixed 8-day delivery periods can do this. This is beneficial for the farmers who share the water through a 7-day roster of turns. Thus an equitable water distribution, the official principle of irrigation in Pakistan, can be restored (Kuper 1997).

Pehur High Level Canal Project

The Upper Swat Canal system is presently irrigating 111,700 ha in the North West Frontier Province of Pakistan. The present scheme for remodeling of the old system and construction of Pehur High-Level Canal started in 1991. The major features of the scheme are- (1) a shift from supply-based irrigation to crop-based irrigation and (2) an addition of 20,000 ha to the command area. IWMI was requested by WAPDA to provide operational support for the Pehur High-Level Canal Project. We examined the proposed design of all three-branch canals. The delivery patterns of distributaries and direct outlets were computed to check the delivery efficiency. The responsiveness of different manual upstream control and automatic downstream control regulators was evaluated (Habib et al. 1996). The canal is currently being constructed taking IWMI's findings into account.

Developing Downstream Gauge Ratings

Most irrigation canals have a substantial number of structures for controlling water levels and discharge rates throughout the system. Many of these flow control structures use gates for regulating the water. A common practice throughout the Indian sub-continent and many other locations, is to place a vertical staff gauge downstream from the flow control structure. Then, a stage-discharge relationship is developed using current meter measurements. This relationship is prepared as a rating table that provides the gate operator with the required water level on the downstream gauge for any discharge rate specified by the irrigation manager.

After calibrating numerous flow control structures, IWMI discovered that the actual discharge rate is usually 15-25 percent less than the downstream gauge rating. In other words, less water is flowing in the canals than what is reported. IWMI carried out research to find solutions to minimize this error. The major conclusion from this research is that the KD-formula is appropriate for developing downstream gauge ratings. A modified gauge rating method using KD formula was developed and presented to provincial irrigation departments (Vehmeyer et al. 1998).

Water Markets in Irrigated Agriculture of Pakistan

There exist very active surface and groundwater markets in Punjab (Meinzen-Dick 1996). As a result of the detailed monitoring of irrigation water use in eight water courses, a better grasp was obtained on canal water transactions that are, in fact, more active than

what has been reported in the literature. Canal water transactions are mainly short-term transactions that involve a part of farmers' water turns and compensate for the variability in watercourse head discharges. Groundwater transactions play a dual role: they increase the water quantities available on farm, and compensate for canal water supply variability. In cases of high unreliability in canal water supply, high conveyance losses, and access to groundwater resources of good quality, farmers within tertiary units develop intensive canal water markets with the sale and purchase of water turns for a week or for the season. The impact of tubewell water markets on farm gross income is significant and estimated at 40% of the actual gross income aggregated for the eight sample watercourses. The impact of existing canal water markets on agricultural production is more difficult to estimate. Short-term flexibility is a very important element of such transactions (Strosser 1997).

Waterlogging, Salinity, Drainage and Groundwater Management

In the Indus Basin of Pakistan, approximately 40,000 ha goes out of production due to salinisation and sodification per annum, and most of these lands are within areas where an expensive irrigation infrastructure is in place. By reclaiming such lands for agricultural production the economic returns from the land as well as the irrigation infrastructure will be improved. IWMI has carried out a number of studies to develop guidelines to mitigate waterlogging and salinity. Only two are reported here.

Low cost water saving salinity reclamation method

In arid and semiarid regions, large tracts of land developed for irrigation are being abandoned each year due to secondary salinization from saline water tables. During non-monsoon months, the mulchability of the surface layers and the hydraulic properties of the subsurface layers influence the rate of salinization of these lands. During monsoon months, the infiltration rate of the surface layers and the depth to the water table control leaching of the surface layers. Mechanical cultivation of the surface layer will increase the mulchability, break the continuity of micro pores between the surface and subsurface layers, and increase the infiltration rate of t he surface layer. These changes to the soil physical properties will minimize the rate of salinization and assist reclamation of these saline soils.

In this respect, the effect of surface cultivation, monsoon rains, depth to water table, and groundwater salinity on secondary salinization are evaluated using a numerical model, SWAP93 (Prathapar and Qureshi, 1999; see also section III). The simulations were performed for three water table regimes (i.e., 0.5 m, 1 m, and 1.5 m). The surface cultivation was done before the monsoon. The results show that with a water table at 1 m or below, abandoned saline soils can be reclaimed by pre-monsoon surface cultivation within a few years. The rate of reclamation is largely independent of the groundwater quality. Continuous pre-monsoon cultivation will prevent re-salinization of these soils. The rate of reclamation is inadequate if the water table is at 0.5 m. The results of this study can be applied to parts of the Punjab and Sindh provinces of Pakistan, where large areas are being abandoned due to secondary salinization. A field experiment carried out by IWMI confirms results obtained with the numerical model.

This method has minimal cost to farmers and will not require additional canal water supplies.

Salinity and Drainage Assessment: Fordwah Eastern Sadiqia Project

The Fordwah Eastern Sadiqia (South) (FESS) project area is located in southeastern Punjab Province. The gross command area under the project is 137,000 ha. The surface water is distributed from distributaries along the Hakra and Malik Branches, from minors and direct outlets. Waterlogging appears mainly in the central and northeast parts of the area. A comparison with previous surveys indicates an increasing trend over time. The Government of Pakistan is constructing a drainage network, for which IWMI provided research support to assess the extent of salinity and waterlogging.

Available literature were reviewed in order to determine trends of salinity/sodicity build-up by comparing the past and present salinity/sodicity research studies. The study reveals that salinity is associated with a high water table and covers about 24% of the area. Also, its efficacy has begun to manifest itself even in the middle reaches of the canals that were previously safe, where farmers are replacing cotton with rice cultivation. Presently, the areas appear normal (water table depth ranging between 150-180 cm, without salinity), but are liable to be infested with waterlogging and salinity in the future. Nearly 18% of the FESS area fall in this category (Aslam et al. 1999).

This study also assessed the spatial and temporal groundwater recharge in the project area. Four years of piezometric data have been analyzed to assess the water table behavior and the monthly net recharge, and to estimate drainage requirements and the areal extent of waterlogging. Results show that the water table in the area is in dynamic equilibrium with a slight rising trend. The months of March, August, and December exhibit peaks of net positive recharge over the distributary commands. The months of July and November also show positive net recharge (Ejaz and Ahmad 1999).

On-Farm Water Management: Evaluation of Bed and Furrow Irrigation Methods

A study was conducted to compare bed-and-furrow irrigation method and basin irrigation method. Overall, 35% less water was applied to fields with bed-and-furrows. Yields in both fields were comparable. However, farmers tend to irrigate fields with bed-and-furrows more frequently. Farmers observed rapid drying of soil in fields with bed-and-furrows. Another factor which influenced frequency and amount of irrigation, was the depth to water table. It is assumed that the contribution of capillary rise allows farmers to irrigate less frequently (Kalwij et al. 1999).

Mexico

This section is based on a final report currently under preparation in Mexico.

Evolution of the Program Strategy

By virtue of its major program of irrigation system transfer, the existence of a relatively large low-income component in the irrigation sector, the availability of appropriate collaborators, and the potential for significant external financial support, Mexico was

identified in the early 1990s as a logical location for work on irrigation management transfer issues. Our strategy involved a three-pronged approach: conducting collaborative research; increasing local and national capacity to address water-related issues; and providing a limited amount of technical assistance.

In the 1994-96 period, studies were carried out in the Mexico sites to examine the agricultural and economic performance of a number of transferred systems. In addition, social and gender equity and environmental impact issues were studied. The initial studies emphasized the technical and economic performance, while later studies stressed institutional and organizational questions, including questions of water rights, and gender access to water. The environmental concerns focused on questions of groundwater utilization and depletion. The findings on management transfer impacts are discussed above in section VI.

In furtherance of the capacity building component of the strategy, efforts were made to involve Mexican graduate students in the field research program. This was intended to increase the pool of individuals trained in field research techniques related to irrigation, and to influence the nature of the research being carried out by the Colegio de Postgraduados (CP) and the INIFAP. M.Sc. students were provided with field research fellowships (through the CIMMYT training program office), logistic and supervisory support. Students were selected from the Centro de Hidrociencias (Center for Water Sciences) and from the Desarrollo Rural Program (Rural Development Program) of the CP. Students from the former institution included engineers and sociologists. Those from the latter had primary interests in the gender issues, and came from the Women's Studies Program. Field logistic support was also provided to a limited number of Ph.D. candidates.

A more indirect approach to capacity building has been participation in local, regional and national conferences and workshops. This participation has included involvement in planning, provision of financial support, and presentation of research results.

By 1996, the widespread prevalence of a severe drought encouraged a shift in emphasis from management of the irrigation systems to issues related to management of the water resource paralleling a similar shift throughout IWMI. While the emphasis shifted, the research questions were still cast in the context of the irrigation sector, with a strong regional (Mexican) input.

The drought provided an opportunity to evaluate the impact of water shortage on the performance of the transferred systems, and these studies continued at the three locations. These included studies of the performance of the water user organizations. Of particular interest were issues related to irrigation system maintenance, since this represents the largest expenditure of funds. In relation to this, research was carried out on computer-assisted decision-making, in collaboration with Hydraulics Research (HR-Wallingford). Together we evaluated the utility of HR's computer-assisted maintenance decision making model (MARLIN) for Mexican conditions. The model was given a Spanish language adaptation and tested in a pilot module.

The capacity building effort is continuing at a relatively high level, with support for both M.Sc. and Ph.D. studies. In the latter case, the program is responding to the interest of the Ford Foundation in the activities of a major NGO – Alternativas y Procesos de Participación Social – in developing potable water supplies. The study is complementary to IWMI's watershed focus in the Lerma-Chapala basin, being a watershed-based study evaluating the appropriateness of different hydrologic models. Additionally, special conferences were organized by IWMI to present the results of the research program to its collaborators (especially the water users) and to other interested parties.

The technical assistance program includes application of the decision-support system to an irrigation district in the Lerma-Chapala region, including the training of district staff; furnishing of data and understanding of the water quality implications of waste water use to the staff of the Water and Sewer Authority of the City of Guanjuato; and provision of satellite imagery of the Lerma-Chapala Basin to Commission staff.

Knowledge Generation

Prior to IWMI's collaborative research program, information on the performance of transferred irrigation systems in Mexico was based upon assumptions, anecdotes and a questionnaire study carried out by the CP. There were no data-based studies of actual performance. IWMI's studies have challenged conventional wisdom about transfer, and have generated substantial discussion at local and national conferences and other forums.

IWMI's comparative studies have revealed significant differences in the adaptation of Mexico's transfer process to local environments. This ability to adapt is an important element in the success of the transfer program, and other organizations and countries do not generally recognize this aspect of the program as they attempt to adopt the Mexico "model".

The studies of water user organizations revealed serious shortcomings that will affect their financial and institutional sustainability. These have led to recommendations for changes in the water fee structure, to include <u>both</u> fixed (based on access potential to water) and variable (based on water use) components of the structure. The studies also revealed needs for greater transparency of WUA operations, and increased communication with the users. The results of the performance studies have highlighted serious economic and social problems in the irrigation sector, while the water market studies have provided the first understanding of the nature and extent of an increasingly important element of water resource management in Mexico. The studies of WUA performance in relation to maintenance investments raise serious questions about the utility of those investments. Since these represent a large share of association budgets, reevaluation of maintenance priorities is of major importance.

Capacity Building

The pool of individuals trained in field research techniques related to water management has been increased by 18: 16 M.Sc. and two Ph.D.

IWMI Spanish language publications now reach over 200 individuals and organizations throughout the world. Approximately two-thirds are in Latin America, 20 percent in the United States, 13 percent in Europe and a few in other regions.

IWMI staff members have participated in a number of local, national and international forums during which the research findings have been transmitted and discussed.

Training in application of the MARLIN model was provided to Module and SRL staff.

Training in water measurement techniques was provided to INIFAP staff in Lagunera and border regions; similar training was provided to staff of selected modules.

Training and hand-on experience related to the evaluation of water quality has been provided to staff of the Guanjuato City Water Board, and students of the University of Guanajuato.

Turkey

This section is adapted from the final chapter of the final technical report on IWMI's work in Turkey (GDRS and IWMI 1999). Supported largely by the Government of Turkey through a two-year contract with the General Directorate of Rural Services (GDRS), this work produced significant research results while also contributing to capacity building. Some of the research findings are discussed in sections III and IV.

The State of the Gediz Basin

The Project has concluded that at the present time there is no systemic shortage of water within the Gediz Basin. There is sufficient surface water available to meet the needs of both surface and pump irrigation, and, with the possible exception of some short-term seasonal shortages, all other water users have adequate water at present.

They did not in the recent past. The drought of 1989-1994 led to immense pressure on the State Directorate for Irrigation (DSI) from several quarters: irrigated agriculture, wetland preservationists, the water quality lobby and municipalities who wanted increased domestic supplies. By and large it appears that the steps taken to cope with the drought were satisfactory, and it is important to note that the same procedures have been maintained to the present time even though water conditions have improved since 1995.

Field studies looking at current levels of irrigation performance concluded that water is being used with a considerable level of efficiency. This has resulted from lessons learned from all parties as a consequence of the catastrophic drought of 1989-1994 that challenged the ingenuity of policy makers, water managers and water users alike.

The Gediz Basin in its present form represents an efficient and effective model for water allocation and utilization under potentially water short conditions. While different sectors have had to make sacrifices (power generation has suffered, farmers have had to switch to less water-demanding crops, and some birds have died) the net result is a relatively

harmonious and productive use of water that has the potential to be sustainable into the future.

Further, irrigated agriculture in the basin is profitable, adaptable and resilient. Even though irrigated agriculture has to take the brunt of reduced water allocations at sector level, with most benefits going to urban and industrial users, it should be able to remain a strong contributor to the rural and national economy for the foreseeable future.

Integrated Basin Modelling

The project has been successful in demonstrating that different models can be used in an integrated manner to simulate the hydrology of a basin at basin level itself, at irrigation system level and at field level. These simulations are linked so that changes at one level can be assessed at all levels, and can be used for scenario analysis of possible changes internal and external to the basin.

All successful models are presumed to be sufficiently accurate in their own right so that they can not only simulate with a reasonable degree of accuracy the present situation but also predict what may happen when one or more of the input conditions are changed. In most circumstances, however, models are not interlinked: the results are a stand-alone set of data that are not compared with outputs from similar models.

In this project two completely different models have been refined and used to describe the hydrology of the Gediz Basin at three different levels: the basin level, the irrigation system level and the field level. Most importantly, the results from the different approaches are consistent and therefore confirm both the robustness of the models themselves and their capability to describe the results of physical processes.

The SLURP model is a parametric model. It uses physical processes within the vertical water balance and routing of flows from one part of the basin to another, but it has to establish parameters for the behavior of different land cover classes. If these land cover related parameters are unknown, as was the case in the Gediz basin, then it is desirable to have some ground truth in the form of actual river discharges to determine the values of the parameters. It generates information on streamflows as its primary output, but in so doing has also to generate information on evaporation and transpiration which can be used for comparative purposes with other models.

The SWAP model is a physically based model that uses a set of tested equations related to water movement through the soil and the use of water by plants. While it requires site-specific information on soil properties, it does not need detailed calibration or verification because the physical processes are universal. It generates information on movement of water to the aquifer and as lateral flow to other locations, on evaporation and transpiration, and on crop yield.

This project has clearly demonstrated that linking of such models is not only feasible but the results derived therefrom are directly comparable. This is a major step forward in the use of modeling for water resources management.

From this we can derive the following conclusions:

- There is no utility in attempting to develop a single integrated model that assesses basin, irrigation system and field level hydrology: the judicious use of different models can accomplish this task with far less effort than the development of a single model.
- The SLURP model is able to describe the hydrology of a basin without the collection of large amounts of primary or secondary data. Using public domain data from a variety of different sources it can estimate with a considerable degree of accuracy the hydrology of a basin. The only locally sourced data required are climatological data which are not normally available in suitable format from the public domain, apart from the IWMI Atlas which provides average data for any given location. However, the final level of accuracy will be improved if some site-specific information on streamflow is available.
- The SWAP model has proved resilient in that it can be used both in its original uni-dimensional mode and in an aggregated format that simulates the hydrology of an irrigation system.
- The SWAP model, used in both its original unidimensional mode and in its aggregated format, produces data that are directly comparable with those produced by the SLURP model, therefore making it easy to use both models to describe all of the critical elements of the hydrology of a river basin at different scales.
- The aggregated SWAP model at irrigation system level has demonstrated its capacity to calculate values of accepted performance indicators making it an invaluable tool for managers in a wide variety of different environments.
- Scenario analysis shows the impact of climatic change and land use on hydrology and productivity, provide decision-makers information on the effects of changing water allocations between different sectors, and provide assistance to managers who may wish to modify current water allocation and distribution practices at irrigation system level.

These conclusions justify the first objective of the Project, aimed at development of a set of interlinked models for use by policy makers and water managers.

The following recommendations have been proposed:

- The use of the complementary SLURP and SWAP models forms a basis for the evaluation of current and future management of water at basin, irrigation system and field level, and therefore should be utilized in other locations where water management is of increasing importance.
- The use of scenario modeling to look at the impact of changes and interventions should be standard practice for decision-makers because it helps reduce the guesswork involved in predicting future conditions.
- Both SLURP and SWAP are robust models that have shown their capacity to be transferred between different hydrologic and agricultural conditions, and therefore should be adopted in different parts of Turkey and elsewhere.

- Policy makers and water managers should be encouraged to use these interlinked models in their current formats, which are comparatively easy to use and understand, rather than attempt to search for a single integrated model that can describe hydrology at several different levels simultaneously.

Irrigation Performance

From the results of the project we can make the following conclusions:

- Current levels of water allocation are probably sufficient to maintain productive and profitable irrigated agriculture into the future within the areas served by large-scale irrigation systems.
- Water use by irrigating farmers is not excessive: application rates more or less match crop water requirements, there are few signs of head-tail disparities, and virtually all irrigable land is currently under production.
- Apparent inefficiencies by users of surface water are offset by the use of groundwater pumping developed in response to the drought to tap recharged shallow aquifers and drainage flows for productive use.
- Overall efficiency of irrigated agriculture during the main irrigation season is somewhere between 90-95%, much higher than reported efficiencies of close to 60-70% because of widespread pumping of groundwater and re-use of drainage flows.
- If too much pumping and reuse occur, however, low discharges will aggravate water quality problems due to lack of dilution of pollutants.
- The Project has determined values for productivity indicators in terms of kg/m3 and $/m3 that are not readily available for Turkey. These data can be used as a baseline for comparison in future studies on irrigation performance elsewhere in the country.
- Current arrangements for management of irrigation water between DSI, Irrigation Associations, Village Irrigation Committees and individual water users are effective and should not be altered without careful consideration.
- Small-scale irrigation developments in piedmont locations have proved an effective complement to large-scale irrigation developments in the valley floor, and may have higher levels of rate of return on investment. However, they are more vulnerable to dropping water table levels.
- Probable threats to the currently high levels of irrigated agricultural efficiency come from the possibility of lowered water table levels through excessive pumping outside the command areas of large scale irrigation systems, the problem of maintenance of drainage canals, the problem of generation of sufficient funds to repair or replace infrastructure and machinery, pollution of surface water supplies by municipal waste water return flows, and indiscriminate dumping of industrial waste into surface waters.

From these conclusions we suggest the following recommendations:

- The current process of water allocation from Demirkopru Reservoir should continue in its present format. The clear cut rules about when water will be issued, and the policy of running canals at full design discharge provide a clear and stable environment for water users. It would be unwise and almost certainly unproductive

to let current levels of management relax and run the risk of fighting over water when water conditions once again become less favorable.

- Irrigation Associations should make sure they do not limit their activities strictly to canal operations and maintenance, and try to have all irrigating farmers as members. Some IAs charge pump farmers a reduced rate for using canals, others do not. But the result is that unused canal water that augments groundwater is being given away free to farmers who pump groundwater.
- DSI must consider charging the IAs a wholesale rate for water delivered to main and secondary canals. At present DSI has no stake in how canal water is used, and should be involved as part of the monitoring responsibility.
- DSI and IAs must, as a matter of urgency, revise their reporting procedures to include the entire area actually being irrigated. It is impossible to manage basin level water resources effectively if the irrigated areas are under-reported by as much as 40%.
- Village Irrigation Committees should keep a comprehensive list of all farmers using irrigation water and distinguish between canal users and conjunctive users on one hand, and sole-source pump-based farmers on the other.
- A task force should be established to examine the problem of capitalization for major repairs and replacement of expensive machinery by the IAs, and examine the work done elsewhere in the world on Asset Management for Irrigation Associations. At present they have difficulty in meeting these costs and there is a real risk of some systems deteriorating as a result. The task force should consider the extent to which some continued government subsidy is possible or desirable, or whether IAs will have to find ways to pay the full commercial cost of repairs and machinery purchase.
- The lack of clarity over responsibility for maintenance of main and secondary drains requires urgent attention so that both DSI and IAs are clear about their responsibilities. If IAs take over drainage canal O&M then they can levy a drainage charge on all farmers because all farmers benefit.
- Market forces and the commercial sector appear to be well equipped to meet the increasing demand for pressurized irrigation and there is no reason for government to be involved in this process. Farmers do not change to pressurized irrigation in response to water shortage but because they get better quality produce for sale in the market. They are well aware of the potential for pressurized irrigation and make the transition when they feel it profitable, not when government wants them to make the shift.
- There should be continued support for small-scale irrigation improvements. The existing systems appear to be working well, water users can and do pay for the O&M costs, and they have led to important increases in productivity in areas outside the main irrigation systems. The investments should be limited to items that it is difficult for the community to provide out of their own resources, and should be co-financed between government and the community.
- Researchers in other projects should use the baseline data on irrigation performance generated in this Project as a reference framework for comparative performance studies.

Water Management in the Gediz Basin in the Future

The generally favorable assessment of water management in the Gediz Basin makes it possible to propose a number of more specific conclusions that look at the future challenges for water management in the Gediz Basin and, by extension, to other basins that face similar water conditions.

- There is no overall coordinated management of water in the Gediz Basin that allows all interested parties to participate in an open manner in the process of inter-sectoral water allocation. This does not imply DSI is not doing a useful job, but as the pressures increase from urban, industrial, environmental and other groups, there will need to be a more open and transparent system.
- The monitoring procedures that exist do not look at water in an integrated manner. Information on surface water use, groundwater use, water quality, urban and industrial is collected by different departments with different frames of reference, so it is hard to collect an overall view of water conditions in the basin.
- Information on groundwater conditions is particularly difficult to obtain and yet it is critical to the long-term health of water resources in the basin. With a huge and very beneficial increase in the use of groundwater for irrigation, combined with increased demand on groundwater resources for urban and industrial use make it essential that groundwater management be transparent and integrated into overall basin level water management.
- Data on water quality are also difficult to obtain. Water management must be just as concerned with the quality of water as with the quantity of water. Water of unacceptable quality is a net loss to society.
- There is confusion and lack of clarity over regulatory roles of different agencies, particularly those related to volumes to be extracted by different sectors, and quality of return flows that come back into the system.
- The productivity of water in the basin has reached very high levels, tripling over the past nine years. It is unlikely that further dramatic increases can be made, and cuts in water to agriculture will likely result in reduced profits.
- The use of modeling at different levels is an effective Decision Support Tool for policy makers and managers. It enables them to predict the likely consequences of climatic and land use changes on total water supply, to predict the consequences of changed allocation procedures on hydrology, and estimate the cost and benefits of changed allocations to different sectors by utilizing a set of basin level, irrigation systems level and field level performance indicators.
- Because the models used in this Project rely in large measure on public domain remotely sensed data it is not difficult to adapt them to other basins where similar analyses can be undertaken.

Based on these conclusions we recommend the following:

- There should be a basin-wide water management authority established that has responsibility for planning and implementing water allocations between sectors. While DSI should play the main role in this organization, it must include other departments and agencies on an equal basis.

- DSI must maintain and strengthen its current monitoring role, develop a clear regulatory role, and be responsible for reporting results to the basin-level authority. The monitoring must include more comprehensive assessment of groundwater use and extraction, surface and groundwater quality, and actual allocations to each sector.
- The authority is encouraged to make use of accurate models as Decision Support Tools that can help in assessing overall water supply, in allocating water between sectors, and assessing the probably impacts of different allocation strategies.
- There is an urgent need to establish accurate and open monitoring programs for water quality and use by the urban/industrial sectors. Currently available data at public level are inadequate to enable systematic and rational planning to occur.
- If cuts are made in water allocations to the agricultural sector, efforts must be made to protect rural incomes because water productivity is probably close to a maximum.
- The use of integrated basin, irrigation system and field level modeling should be extended to all basins where there is a current or predicted water shortage.
- The procedures developed in the Project, published separately as manuals, should be used together with baseline data from this project as the basis for further comparative performance assessment studies in Turkey.

India

Over the years, IWMI has been involved in a variety of activities in India, even though it has never had a residential presence there. During the last five years, IWMI has completed research in the area of irrigation performance, satellite remote sensing, irrigation management transfer, gender analysis, and mosquito control and water savings through alternating wet and dry irrigation. IWMI has collaborated with a wide number of partners including the Indian Council on Agricultural Research (ICAR), ICID, Indian Institute of Management at Ahmedabad (IIMA), National Remote Sensing Agency (NRSA), Central Soil Salinity Research Institute (CSSRI), Karnal, and the Water Resources Departments of Haryana, Maharashtra, Karnataka, Tamilnadu, Gujarat, and Bihar. Given below are some of the important research studies that IWMI has undertaken, workshops conducted and publications. Reference is made to some of the research results in the previous sections (III-VI).

Irrigation Management Transfer in India

IWMI in collaboration with Indian Institute of Management, Ahmedabad (IIMA) carried out a research study of the Status of Irrigation Management Transfer in India during 1994-96. The basic goal of the study was to survey policies and activities being carried out in different parts of India.

The specific goals of the study were to:

- Determine the respective management roles of government agencies, farmers and other private entities in selected agency and jointly managed irrigation systems in the sample states.
- Develop detailed descriptions of the processes of the most important types of turnover, including determination of the major constraints to achieving turnover.

- Evaluate the performance, including resource mobilization and sustainability, outputs and equity of turned over systems.

The study focussed on six states:

* Bihar in eastern India
* Haryana in northwest India
* Gujarat and Maharashtra in western India
* Kerala and Tamilnadu in southern India

The research results, summarized in section VI, were widely disseminated through regional and national workshops and published as a book titled "Irrigation Management Transfer in India: Policies, Processes and Performance" by Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi (Brewer et al. 1999). Copies were distributed widely among practitioners, policy makers and research and educational institutions.

The Impact of Participatory Management on Maintenance Performance

IWMI in association with IIMA studied of the impacts of irrigation management transfer in selected sites in Maharashtra. In large scale government irrigation systems the Maharashtra Irrigation Department is transferring operations and maintenance responsibilities of minor canals to water users associations. Maintenance is the single largest cost in most irrigation systems. Transfer of maintenance responsibilities to farmers is thus of major importance to the success of the management transfer policy from the government's point of view. However, given the concern for inadequate maintenance, the question we sought to answer is whether management transfer will help improve irrigation system maintenance.

For the study, four minor canals, two in Mula command and two in the Bhima command were selected. Both irrigation schemes are large schemes in the western portion of Maharashtra; Mula command area is 80,180 ha and Bhima is 112,490 ha. Bhima is newer than Mula. Irrigation began in Mula in 1971 while it began in Bhima only in 1980.

In this study, we found that the transferred sites showed far better maintenance performance than the non-transferred sites.

The difference in maintenance performance is not due to a difference in resources expended nor to the repairs carried out as part of the transfer process, but is due to clear differences in maintenance management process. This is true despite the fact that the total resources expended were very low and were tightly constrained. We conclude from this study that small differences in maintenance management process can lead to major differences in maintenance performance within tight resource constraints even without adoption of elaborate procedures such as "asset management".

One-day Workshop to Disseminate IWMI's Research Results of India Studies

A one-day workshop to disseminate IWMI's research results of India studies was hosted by the Central Water Commission (CWC) at New Delhi on 24 September 1998. About 50 participants from state and central government organizations and funding agencies (Ford, DFID, World Bank) attended the workshop.

Presentations were given on performance, remote sensing and some applications to Bhakra, the Bhadra and Bhakra studies, and Information Technology for Irrigation Sytems (ITIS). The team felt that the following messages were successfully delivered: 1) remote sensing is a cost effective and efficient tool for performance studies, and 2) IWMI can contribute significantly to this work.

A Pilot Project Study on Alternate Wet and Dry Irrigation to Control Vectors in Periyar-Vaigai Project, Tamilnadu, India

Entomologists have proposed for many years that alternate wet and dry irrigation (AWDI) would control mosquitoes breeding in paddy fields and irrigation channels (see section V). Until recently, the idea of AWDI was not widely accepted by the irrigation community, but AWDI has now become a standard management procedure in at least two systems in India in order to conserve water. The stage is set to determine the effect of this environmental management technique that has significant health benefits and has an important contribution to make to sustainable development.

IWMI in collaboration with the Tamilnadu Agricultural Institute and Central Research Institute on Medical Entomology, both in Madurai, is implementing a research project on "Strategies for Vector Control, Conserving Water and Increasing Food Security" in Periyar-Vaigai Project to evaluate the impact of different water management practices on vector breeding, water conservation and rice yield. The details of three different irrigation treatments tested are:

- Continuous submergence (farmers' practice)
- Irrigation to 5 cm one day after disappearance of ponded water
- Rotational water supply (4 days 'on' and 3 days 'off').

The study is an on-going one with one season of data collection (October 1998 to February 1999) completed. The results are encouraging: rice yields in AWDI has increased by 10% and water saving by 22% compared to farmers' practice. However, the vector reduction is only marginal during this season.

Satellite Remote Sensing

Monitoring of scarce water resources is becoming a serious issue for several countries including India. There is increasing pressure among water managers to allocate less water to agriculture – which uses almost 80 percent of currently available water supplies – and more to domestic and industrial uses.

In response to meeting this challenge of growing more food with less water, IWMI is working with its Indian collaborators on increasing agricultural productivity of water

through better management of irrigation and water basin systems. Satellite Remote Sensing is becoming a vital tool in this endeavor to:

- improve the diagnosis of regional scale practices
- evaluate the success of organizational, socio-economic and technical interventions on irrigation system performance
- establish water accounts methods to determine water use and scarcity at the basin level
- identify strategies to increase the productivity of water.

The strength of IWMI's research lies in combining this detailed data into a relevant information set to support decision making by managers of water resources.

IWMI applied remote sensing to study trends in irrigation system performance at various levels of canal hierarchy and to assess the impact of rehabilitation interventions under the National Water Management Project of 100,000 ha Bhadra Reservoir Project.

Using multiyear Indian Satellite Remote Sensing data from 1987-1997, IWMI collaborated with the National Remote Sensing Agency (NRSA) to develop a rice-yield-NDVI model. Remote sensing data is integrated in a GIS framework with ground water, precipitation, canal networks, and canal water deliveries. The information was used to identify problem distributaries that are then diagnosed to identify causes for under-performance.

Remote sensing was used in the Bhakra project, Haryana to characterize current performance level of the system, pinpoint problem areas, and identify issues relating to the long-term sustainability of the system.

The research results of these two studies were discussed with the project level officials as well as state level policy makers of the respective states and also two national level workshops were conducted to disseminate the efficient and cost-effective techniques of SRS to monitor performance of irrigation projects. The results of the research are discussed above, in section IV.

Iran

The Iran-IWMI Collaborative Project is undertaken jointly between the Iranian Agricultural Engineering Research Institute (IAERI) in Karaj and IWMI to examine aspects of water management at river basin, irrigation system and field level. Primary activities are focussed on the Zayandeh Rud basin, Esfahan Province in conjunction with staff from the Esfahan Agricultural Research Station.

The project became fully active with the First Planning Mission held in August-September 1998. Since that time there have been three additional missions by IWMI staff to Iran that have consolidated the program further. This report summarizes the progress made to date.

First Planning Mission (August-September 1998)

A seven-member planning mission visited Iran and met with officials and researchers in both Teheran and Esfahan. Five main components of the project were identified and for each component a work plan was developed for the period 1998-1999:

1. Basin level hydrological modeling
2. Irrigation system management
3. Field level water management
4. Salinity and groundwater studies
5. Geographic Information Systems and database development.

The primary focus of activities in the initial stage of the project was collection of sufficient information to permit identification of key issues and enable detailed studies to be undertaken.

Following this mission it was agreed to schedule a series of visits by IWMI staff to Teheran and Esfahan that would meet the objectives of the project. Much of the focus of subsequent work was been along these lines.

First Training Mission (November 1998)

A two person team visited Teheran and Esfahan to review progress since the planning mission. Progress had been limited because computers had not been provided, and there were some difficulties in obtaining baseline data from other government agencies. Both of these issues were largely overcome during the mission.

Based on the data collected up to that time the mission focussed on training in two main areas:

(a) data collection, processing, and analysis, together with the establishment of a systematic database; and
(b) an introduction to use of several computer packages, including Windows, Excel and the ILWIS GIS program.

All data collected to date were consolidated, included in the Mission Report and copied to CD-ROMs. Copies of the CD-ROMs and Mission Report were also given to IAERI in Karaj.

Second Training Mission (February 1999)

The same two-person team undertook this second training mission. Good progress had been made in data collection since the previous mission, and much of the focus of training was on the use of the ILWIS GIS package and further development of the project database.

To try to facilitate better communication with IWMI staff between training missions, an e-mail system was established and additional computer facilities provided.

Each of the working groups established during the first training mission were able to accomplish a set of tasks relevant to their discipline, and the results incorporated into the Mission Report. This report was provided to IAERI in Karaj together with CD-ROMs containing all data collected during the project.

Overseas Training (July 1999)

Efforts were made to identify opportunities for training outside Iran, taking into account the financial constraints facing the Government. In July 1999 Mr. Mehdi Akbari, Project Coordinator in Esfahan, attended a 10-day training program in Menemen, Turkey, on the use of the SWAP model for determining soil-plant-water relationships and calculation of water balance at field and farm level.

Third Training Mission (August 1999)

Dr. Gieske (of ITC, Netherlands) undertook a third training mission to Esfahan. This program focussed on remote sensing, particularly Landsat and NOAA images, to establish capability to produce land use maps, vegetation indices and other images related to temperature and radiation. The facilities at Esfahan were used to download a series of NOAA images that formed the basis for much of the training undertaken.

The report resulting from this mission was provided to IAERI together with two CD-ROMs containing all data collected and processed.

Proposed Future Activities

Following the experience of the first year of the collaboration, the time is now ready for a second planning mission to propose activities for the year 2000. An improved budget from the Government of Iran plus relocation of IWMI staff from Turkey to Sri Lanka make it possible to increase the level of input and interaction from IWMI.

The overall content of the project should not require serious readjustment at this stage, although progress in the areas of field studies, salinity and groundwater requires more input.

Nepal

IWMI has had a presence in Nepal since the 1980s. Our research has contributed significantly in the areas of documenting the existence, importance, and management processes of farmer managed irrigation systems (FMIS); devising methodologies to support FMIS; and in providing key research backstopping in the field of irrigation. IWMI's office was managed by internationally recruited staff through 1995.

We now operate in a non-resident mode and work is supported by modest donor grants. Staff from headquarters manage and contribute to projects. The Department of Irrigation has provided office space, and IWMI has hired a local researcher and administrative staff. There is a Memorandum of Understanding between the Government of Nepal and IWMI, and a Consultative Committee that meets every six months. IWMI is presently implementing a project on 'Process and Performance of Management Transfer,' and more

recently, research on gender in irrigation. By this presence, the local researcher and visiting IWMI scientists are able to dialogue with various groups involved in water resources development in Nepal.

IWMI's main achievements in Nepal during the last five years have been in providing policy and implementation support to the Ministry of Water Resources and the Department of Irrigation; and in building the capacity of Nepali researchers and staff. IWMI and collaborators provide locally relevant research support to the Department of Irrigation and Water Users Associations on management transfer and gender issues. Findings are presented and discussed by each group to develop better implementation processes, and policies within the government. For example, we understand that through this process, some of IWMI's recommendations on irrigation service fees are to be included in the new irrigation regulations and policy. Papers are now being prepared based on the findings for an international audience.

IWMI is now completing research projects on gender and management transfer. New research activities at the basin level are beginning with one basin selected in the hills (the Indrawati) and one in the Tarai (the East Rapti). We understand that results of these studies will provide input into the Nepal National Water Resources Strategy, which will be prepared next year. IWMI also intends to do research on Small Holder Water Management Systems in Nepal.

References

Abernethy, C.L. and H. Sally. 1999. Experiences of some government-sponsored organisations of irrigators in Niger and Burkina Faso, West Africa. *Paper presented at the workshop on Government Actions Towards effective Irrigators' Organizations.* Vientiane, Laos, March 1999.

Abernethy, C.L., H. Sally, K.A. Lonsway and C. Maman. 1999 [forthcoming]. *Farmer-based financing of operations in Niger Valley irrigation schemes*, Research Report, IWMI.

Amerasinghe, F.P., F. Konradsen, K.T. Fonseka, P.H. Amerasinghe. 1997. Anopheline (Diptera: culicidae) breeding in a traditional tank-based village ecosystem in northcentral Sri Lanka. *Journal of Medical Entomology,* 34: 290-297.

Amerasinghe, P.H., F.P. Amerasinghe, F. Konradsen, K.T. Fonseka, R.A. Wirtz. 1999. Malaria vectors in a traditional dry zone village in Sri Lanka. *American Journal of Tropical Medicine and Hygiene*, 60: 421-429.

Amerasinghe, U. A., R. Sakthivadivel and H. Murray-Rust. 1998. *Impact assessment of rehabilitation intervention in the Gal Oya Left Bank*. Research Report 18. Colombo, Sri Lanka: International Water Management Institute.

Amerasinghe, U. A., L. Mutuwatte and R.Sakthivadivel. 1999. *Water scarcity variations within a country: A case study of Sri Lanka*. Research Report 32. Colombo, Sri Lanka: International Water Management Institute.

Aslam, M., A. Hamid, A. Hussain and M. Tabassam. 1999. *Soil Salinity-sodicity and land use suitability in the Fordwah Eastern Sadiqia (South) irrigated area.* Report No. R-81. Lahore, Pakistan: Pakistan National Program-International Water Management Institute.

Bakker, M., R. Barker, R. Meinzen-Dick, and F. Konradsen. 1999. *Multiple uses of water in irrigated areas; A case study from Sri Lanka.* SWIM Paper 8. Colombo, Sri Lanka: International Water Management Institute.

Bakker, M. and Y. Matsuno (forthcoming). Valuing ecological services of irrigation water: framework for an irrigation-wetland system in Sri Lanka. *Irrigation & Drainage Systems.*

Bandaragoda, D. J., and G. R. Firdousi. 1992. *Institutional factors affecting irrigation performance in Pakistan: research and policy priorities.* IIMI Country Paper - Pakistan No.4. Colombo, Sri Lanka: International Irrigation Management Institute.

Bandaragoda, D. J.; and Rehman, Saeed ur. 1994. *Institutional Perspectives of Land Reclamation Operations in the Punjab: A Case Study of the Lower Chenab Canal (East) Circle*. Working Paper 28, Colombo, Sri Lanka: International Irrigation Management Institute.

Bandaragoda, D.J. and M.Y. Memon. 1997. *Moving towards participatory irrigation management.* Report No. R-26. Lahore, Pakistan: Pakistan National Program-International Water Management Institute.

Bandaragoda, D. J. 1998. *Need for institutional impact assessment in planning irrigation system modernization*. Research Report 21, Colombo, Sri Lanka: International Water Management Institute.

Bandaragoda D. J.; and Rehman, S. U. 1998. *Design and practice of water allocation rules: lessons from Warabandi in Pakistan's Punjab.* Research Report 17. Colombo, Sri Lanka: International Water Management Institute.

Bandaragoda, D. J. 1999 [forthcoming]. Institutional change and shared management of water resources in large canal systems: Results of an action research program in Pakistan, Research Report. International Water Management Institute.

Bastiaanssen, W. G. M., S. Thiruvengadachari, R. Sakthivadivel, and D. J. Molden. 1999a. Satellite Remote Sensing for Estimating Productivities of Land and Water. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 181-196.

Bastiaanssen, W.G.M., D.J. Molden, S. Thiruvengadachari, A.A.M.F.R. Smit, L. Mutuwatte, and G. Jayasinghe. 1999b. *Remote Sensing and Hydrologic Models for Performance Assessment in Sirsa Irrigation Circle, India*. Research Report 27. Colombo, Sri Lanka: International Water Management Institute.

Bastidas, Elena P. 1999. *Gender issues and women's participation in irrigated agriculture: the case of two private irrigation canals in Carchi, Ecuador*. Research Report 31. Colombo, Sri Lanka: International Water Management Institute.

Batchelor, C., J. Cain, F. Farquharson, and J. Roberts. 1998. *Mimproving water utilization from a catchment perspective.* SWIM Paper 4. Colombo, Sri Lanka: International Water Management Institute.

Baume, J.P., H. Sally, P.O. Malaterre, and J. Rey. 1993. *Development and field installation of a mathematical simulation model in support of irrigation canal management*. Research Paper, Colombo, Sri Lanka: International Irrigation Management Institute.

Bhutta, M. N., and E. J. Vander Velde. 1992. Equity of water distribution along secondary canals in Punjab, Pakistan. *Irrigation and Drainage Systems*, Vol 6: 161-177.

Brewer, J., S. Kolavalli, A.H. Kalro, G.Naik, S Ramnarayan, K.V. Raju, R. Sakthivadivel. 1999. *Irrigation management transfer in India: Policies, processes and performance.* New Delhi: Oxford & IBH Publishing Co. Pvt. Ltd.

Calder, I.R. 1998. *Water-resource and land-use issues.* SWIM Paper 3. Colombo, Sri Lanka: International Water Management Institute.

Cleaver, Francis (guest editor). 1998. Choice, complexity, and change: gendered livelihoods and the management of water. Agriculture and Human Values. *Journal of Agriculture, Food, and Human Values Society*. Vol. 15. No. 4. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Coward, E.W. Jr. 1980. Management themes in community irrigation systems. In: *Irrigation and agricultural development in Asia: Perspectives from the social sciences*, ed. E. Walter Coward Jr. Ithaca, New York, USA: Cornell University Press

Dembélé, Y. 1999. *Evaluation des performances et diagnostic sommaire de périmètres irrigués au Sourou par l'application de la méthodologie IIMI/PMI-BF*. Unpublished Report: Autorité de Mise en Valeur de la Vallée du Sourou, Burkina Faso.

Droogers, P., and G.W. Kite. 1999. Water productivity from integrated basin modeling. *Irrigation and Drainage Systems* (in press).

Droogers, P., W.G.M. Bastiaanssen, M. Beyazgül, Y. Kayam, G.W. Kite, and H. Murray-Rust. 1999. Agro-hydrological analyses of an irrigation system in Western Turkey using simulation modeling. *Agricultural Water Management* (in press).

Droogers, P., G. Kite, and H. Murray-Rust. 1999. Use of simulation models to evaluate irrigation performances including water productivity, risk and system analyses. *Irrigation Science* (submitted).

Ejaz, M.S., and H.M.N. Ahmad. 1999. *Spatial and temporal assessment of groundwater recharge in the Fordwah Eastern Sadiqia (south) project area*. Report No. R-86. Lahore, Pakistan: Pakistan National Program-International Water Management Institute.

FAO and IWMI. 1999. *Transfer of irrigation management services: Guidelines*. Rome, Italy: FAO

Frederiksen, H. D. and R.J. Vissia. 1998. *Considerations in formulating the transfer of services in the water sector.* Colombo, Sri Lanka: International Water Management Institute.

Garces-Restrepo, C. and L.A. Mora. 1997. Application of external performance indicators to assess irrigation management transfer in three irrigation districts in Colombia. *Paper presented at the International Workshop on Irrigation Performance*, Mendoza, Argentina.

GDRS (General Directorate of Rural Services) and IWMI. 1999 [forthcoming]. The Gediz River study, *Final Project Report*

GDRS (General Directorate of Rural Services) and IWMI. 1999 [forthcoming]. The Gediz River study, *Irrigation in the basin context.*

Godaliyadda, G.G.A., D.Renault, M. Hemakumara and I. W. Makin. [forthcoming] Improving performance of Irrigation Systems Operation in Sri Lanka, *Irrigation and Drainage Systems*.

Guerra, L.C., S.I. Bhuiyan, T.P. Tuong, and R. Barker. 1998. *Producing more rice with less water from irrigated systems.* SWIM Paper 5. Colombo, Sri Lanka: International Water Management Institute.

Habib, Z., K. Pongput and G.V. Skogerboe. 1996. *Unsteady flow simulation of the designed Pehur High Level Canal and proposed remodeling of Machai and Maria Branch canals, North West Frontier Province, Pakistan*. Report No. R-20, Lahore, Pakistan: Pakistan National Program-International Irrigation Management Institute.

Habib, Z., S.K. Shah, M. Kalemullah, A. Vabre, M. Ahmed, and A. Sophyani. 1999. *Hydraulic simulations to evaluate and predict design and operation of the Chasma*

Right Bank Canal. Report No. R-79. Lahore, Pakistan: Pakistan National Program-International Water Management Institute.

Horst, L. 1998. *The dilemma of water divisions: Considerations and criteria for irrigation system design*. Colombo, Sri Lanka: International Water Management Institute.

Hunt, R.C. 1989. Appropriate social organizations? Water users' associations in bureaucratic canal irrigation systems. *Human Organization* 48:79-90.

IIMI. 1996. *Methodologie d'évaluation des performances et de diagnostic des systèmes irrigués.* Ouagadougou, Burkina Faso : Institut International du Management de l'Irrigation.

ITIS. 1998. Modernisation of irrigation system operations. *Proceedings of the fifth ITIS network meeting*. Aurangabad, India.

IWMI, 1999a. *Water for Food Vision 2025 Policy Dialogue Model (PODIUM).* http://www.cgiar.org/iwmi/V2025P1.htm

IWMI, 1999b. *World Water and Climate Atlas.* http://www.cgiar.org/iwmi/atlas.htm

IWMI. 1999c. *IWMI's strategic plan for 2000 and beyond*. Colombo, Sri Lanka, International Water Management Institute.

IWMI. 2000 [forthcoming]. *Fostering performance-oriented management of irrigation schemes: Results and experiences from the Research Program on Irrigation Performance*. Colombo, Sri Lanka: International Water Management Institute.

Jensen, P.K., Y. Matsuno, W. van der Hoek, and S. Cairncross. [forthcoming]. Limitations of irrigation water quality guidelines from a multiple use perspective. *Irrigation & Drainage Systems.*

Jinapala, K., J.D. Brewer, and R. Sakthivadivel. 1996. *Multi-level participatory planning for water resources development in Sri Lanka.* Gatekeeper Series no. 62. International Institute for Environment and Development, Sustainable Agriculture Programme London: International Institute for Environment and Development.

Johnson, S.H., D. L. Vermillion, J.A. Sagardoy. 1995. *Irrigation management transfer: Selected papers from the international conference on irrigation management transfer, Wuhan, China, 20-24 September, 1994,* Rome: Food and Agriculture Organization and International Irrigation Management Institute.

Johnson, Sam III. 1997. *Irrigation management transfer in Mexico: A strategy to achieve irrigation district sustainability*, Research Report 16. Colombo, Sri Lanka: International Irrigation Management Institute.

Jordans, H., and M.Z. Zwarteveen. 1996. *A well of one's own. Gender analysis of an irrigation program in Bangladesh.* IIMI Bangladesh Country Paper No. 1. Colombo, Sri Lanka: International Irrigation Management Institute and Grameen Krishi Foundation.

Kalwij, I.M., Z.I. Mirza, A. Amin and A. Hameed. 1999. *Disseminating the Bed-and-Furrow irrigation method for cotton cultivation in the Hakra 4R distributary in*

collaboration with the Water User Federation. Report No. R-83. Lahore, Pakistan: Pakistan National Program-International Water Management Institute.

Keller, A., J. Keller and D.W. Seckler. 1996. *Integrated water resources systems: Theory and policy implications*. Research Report 3. Colombo, Sri Lanka: International Water Management Institute.

Kijne, J.W. 1996. *Water and salinity balances for irrigated agriculture in Pakistan.* Research Report 6. Colombo, Sri Lanka: International Water Management Institute.

Kijne, J.W., S.A. Prathapar, M.C.S. Wopereis and K.L. Sahrawat. 1997. *How to manage salinity in irrigated lands: A selective review with special reference to irrigation in developing countries*. SWIM Paper 2. Colombo, Sri Lanka: International Irrigation Management Institute.

Kite, G.W., and P. Droogers. 1999a. Comparing evapotranspiration estimates from satellites, hydrological models and field data. *J. of Hydrology* (in press).

Kite, G.W. and P. Droogers. 1999b. Irrigation modelling in a basin context. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 44-54

Kloezen, W. H., C. Garces-Restrepo and Sam H. Johnson III. 1997. *Impact assessment of management transfer in the Alto Rio Lerma irrigation district, Mexico*, Research Report 15. Colombo, Sri Lanka: International Irrigation Management Institute.

Kloezen, W. and C. Garces-Restrepo. 1998. *Assessing irrigation performance with comparative indicators: The case of Rio Alto Lerma irrigation district, Mexico.* Research Report 11. Colombo, Sri Lanka: International Water Management Institute.

Konradsen, F., W. van der Hoek, P.H. Amerasinghe, F.P.Amerasinghe, and K.T.Fonseka. 1997a. Household responses to malaria and their costs: a study from rural Sri Lanka. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 91: 127-130.

Konradsen, F., W. van der Hoek, P.H. Amerasinghe, F.P. Amerasinghe. 1997b. Measuring the economic cost of malaria to households in Sri Lanka. *American Journal of Tropical Medicine and Hygiene,* 56: 656-660.

Konradsen, F., Y. Matsuno, F.P. Amerasinghe, P.H. Amerasinghe, W. van der Hoek. 1998. *Anopheles culicifacies* breeding in Sri Lanka and options for control through water management. *Acta Tropica*, 71: 131-138.

Konradsen, F., P. Steele, W. van der Hoek, P.H. Amerasinghe, and F.P. Amerasinghe. 1999. Cost of malaria control in Sri Lanka. *Bulletin of the World Health Organization*, 77: 301-309.

Konradsen, F., W. van der Hoek, P.H. Amerasinghe, F.P. Amerasinghe, D.A. Perera. 2000 [forthcoming]. Village treatment center for malaria: community response in Sri Lanka. *Social Science and Medicine*.

Konradsen, F., F.P. Amerasinghe, W. van der Hoek, and P.H. Amerasinghe. 2000 [forthcoming] *Malaria in Sri Lanka: Current Knowledge on Transmission and Control*.

Kuper, M. 1997. *Irrigation management strategies for improved salinity and sodicity control*. Ph.D. Dissertation. Wageningen Agricultural University, Netherlands.

Lacroix, M., G. Kite and P. Droogers. 1999. Distributed basin modeling using only public-domain datasets. *Water Resources Research* (submitted).

Matsuno, Y., W. van der Hoek, and M. Ranawake (eds.). 1998. Irrigation Water Management and the Bundala National Park. *Proceedings of the Workshop on Water Quality of the Bundala Lagoons,* Battaramulla, 3 April 1998.

Matsuno, Y., F. Konradsen, M. Tasumi, W. van der Hoek, F.P. Amerasinghe, P.H. Amerasinghe. 1999. Control of malaria mosquito breeding through irrigation water management. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 93-105.

McKinney, D.C., X. Cai, M.W. Rosegrant, C. Ringler, and C.A. Scott. 1999. *Modeling water resources management at the basin level: Review and future directions.* SWIM Paper 6. Colombo, Sri Lanka: International Water Management Institute.

Meinzen-Dick, R. 1996. *Groundwater markets in Pakistan: Participation and productivity*. Research Report 105. Washington D.C., USA: International Food Policy Research Institute.

Meinzen-Dick, R., and M. Z. Zwarteveen. 1999. Gendered participation in water management: issues and illustrations from water users associations in South Asia. In: Beck, Tony, Pablo Mose, and Barrie Morrison (eds) *The cooperative management of water resources in South Asia.* Vancouver, Canada: Centre for India and South Asian Research, Institute of Asian Research, University of British Columbia.

Meinzen-Dick, R., and M. Bakker. 1999. Irrigation systems as multiple-use commons: water use in Kirindi Oya, Sri Lanka. *Agriculture and Human Values,* 16:281-293.

Merrey, D.J. 1996. *Institutional design principles for accountability in large irrigation schemes*. Research Report 8. Colombo, Sri Lanka: International Irrigation Management Institute.

Merrey, D.J. 1997. *Expanding the frontiers of irrigation management research: Results of research and development at the International Irrigation Management Institute, 1984 to 1995*. Colombo, Sri Lanka: International Irrigation Management Institute.

Merrey, D.J. 1998. Governance and institutional arrangements for managing water resources in Egypt. In *Mollinga et al (Eds.) Water control in Egypt's canal irrigation: A discussion of institutional issues at different levels*. Liquid Gold 1998 Paper 3. Wageningen, The Netherlands: Wageningen Agricultural University & International Institute for Land Reclamation and Improvement.

Merrey, Douglas J., and Shirish Baviskar (eds). 1998. Gender analysis and reform of irrigation management: Concepts, cases and gaps in knowledge. *Proceedings of the Workshop on Gender and Water*. September 1997. Colombo, Sri Lanka: International Water Management Institute.

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

Molden, D.J., R. Sakthivadivel, C.J. Perry, C. De Fraiture and W.H. Kloezen. 1998. *Indicators for comparing performance of irrigated agriculture systems*. Research Report 20. Colombo, Sri Lanka: International Water Management Institute.

Molden, D.J. and R. Sakthivadivel. 1999. Water accounting to assess use and productivity of water. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 55-71.

Molden, D.J., R. Sakthivadivel, and J. Keller. 1999. The use of hydronomic zones for interpreting irrigation performance in a basin context. *Paper presented at the USCID Conference on Benchmarking Irrigation System Performance Using Water Measurement and Water Balances*. San Luis Obispo, March 1999.

Molden, D.J.,R. Sakthivadivel and Z. Habib. 1999. Basin water use, conservation and productivity: Examples from South Asia. *Paper presented at the 17th ICID Congress*. Granada, Spain.

Murray-Rust, H., R. Sakthivadivel, and U.A. Amerasinghe. 1999. Impact assessment of organizing farmers in the Gal Oya Left Bank Irrigation Scheme, Sri Lanka. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 197-217.

Mutero, C.M., H. Blank, F. Konradsen, W. van der Hoek. [forthcoming]. Water management for controlling anopheles breeding in rice irrigation schemes in Kenya.

Ong, C., J. Kerr, N. van de Giesen, and T. Steenhuis. 1999 [forthcoming]. *Synthesis of watershed research in CG Centers*. SWIM Paper 9. Colombo, Sri Lanka: International Irrigation Management Institute.

Ostrom, Elinor. 1992. *Crafting institutions for self-governing irrigation systems*. San Francisc, California, USA: Institute for Contemporary Studies Press

Oweis, T., A. Hachum, and J. Kijne. 1999. *Water harvesting and supplemental irrigation for improved water use efficiency in dry areas.* SWIM Paper 7. Colombo, Sri Lanka: International Water Management Institute.

Perry, C. J. 1995. Determinants of function and dysfunction in irrigation performance, and implications for performance improvement. *International Journal of Water Resources Development*, 11(1):25-38.

Perry, C.J. 1996. *The IIMI water balance framework: A model for project level analysis.* Research Report 5. Colombo, Sri Lanka: International Irrigation Management Institute.

Perry, C.J., 1996. *Alternative approaches to cost sharing for water service to agriculture in Egypt.* Research Report 2. Colombo, Sri Lanka: International Irrigation Management Institute.

Perry, C. J., D. Seckler, M. Rock. 1997. *Water as an economic good: A solution, or a problem.* Research Report 14. Colombo, Sri Lanka: International Irrigation Management Institute.

Perry, C. J. 1999. The IWMI water resources paradigm: Definitions and implications. *Agricultural Water Management*, 40(1):45-50.

Plusquellec, H., C. Burt, and H.W. Wolter. 1994. *Modern water control in irrigation: Concepts, issues, and applications*. Washington, DC, USA: World Bank. (World Bank technical paper no.246)

Postel, Sandra. 1999. *Pillar of Sand: Can the irrigation miracle last?* New York: WW Norton & Co.

Prathapar, S.A. and A.S. Qureshi. 1999. Modeling the effects of deficit irrigation on soil salinisty, depth to water table and transpiration in semi-arid zones with monsoonal rains. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 141-159.

Prathapar, S.A. and A.S. Qureshi. 1999. *Mechanically reclaiming abandoned saline soils: A numerical evaluation.* Research Report 30. Colombo, Sri Lanka: International Water Management Institute.

Renault, D., M. Hemakumara and D. Molden. 1999. Importance of evaporative depletion by non-crop vegetation in irrigated areas of the humid tropics. *Paper presented at the USCID Conference on Benchmarking Irrigation System Performance Using Water Measurement and Water Balances*. San Luis Obispo, March 1999.

Renault, D. 1999. Offtake sensitivity, operation effectiveness, and performance of irrigation systems. *Journal of Irrigation & Drainage Engineering*. 125(3): 137-147.

Renault, D. and G.G.A. Godaliyadda. 1999. *Generic typology for irrigation systems operation*. Research Report 29. Colombo, Sri Lanka: International Water Management Institute.

Renault, D. and H.M. Hemakumara. 1999. Irrigation offtake sensitivity. *Journal of Irrigation and Drainage Engineering*. 125(3): 131-136.

Renault, D. and P.W Vehmeyer. (Forthcoming). On reliability in irrigation service: Preliminary concepts and application. *Irrigation and Drainage Systems.*

Renault, D. and I.W. Makin. 1999. *Modernization irrigation operations: Spatially differentiated resource allocations.* Research Report 35. Colombo, Sri Lanka: International Water Management Institute.

Renwick, M. et al. 1999. (forthcoming). *Valuing alternative uses of water in a multiple use irrigation system: Irrigated agriculture and reservoir fisheries.* Research Report. IWMI.

Sakthivadivel, R. and O.T. Gulati. 1997. Assessing management intervention impacts with IIMI's minimum set of comparative indicators. *Paper presented at the International Workshop on Irrigation Performance*. Mendoza, Argentina.

Sakthivadivel, R. N. Fernando and J.D. Brewer. 1997. *Rehabilitation planning for small tanks in cascades: A methodology based on rapid assessment*. Research Report 13. Colombo, Sri Lanka: International Water Management Institute.

Sakthivadivel, R., C. de Fraiture, D.J. Molden, C.J. Perry and W.H. Kloezen. 1999a. Indicators of land and water productivity in irrigated agriculture. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 161-180

Sakthivadivel, R., S. Thiruvengadachari, U. Amarasinghe, W. G. M. Bastiaanssen, and D. Molden. 1999b. *Performance evaluation of the Bhakra irrigation system, India, using remote sensing and GIS techniques.* Research Report 28. Colombo, Sri Lanka: International Water Management Institute.

Sakthivadivel, R. and J.D. Brewer. 1999. Water resources development planning in a basin context in the absence of good hydrological data: An example from Sri Lanka. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 73-91.

Sakthivadivel, R., S. Thiruvengadachari, and U. Amarasinghe. 1999. *Modernization using the structured system design of the Bhadra reservoir project, India: An intervention analysis*. Research Report 33. Colombo, Sri Lanka: International Water Management Institute.

Samad, M and D.L. Vermillion. 1999a. *Assessment of participatory management of irrigation schemes in Sri Lanka; Partial reforms, partial benefits.* Research Report 34. Colombo, Sri Lanka: International Water Management Institute.

Samad, M and D.L. Vermillion. 1999b. An assessment of the impact of participatory irrigation management in Sri Lanka. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 219-240.

SCOR. 1999. Shared Control of Natural Resources (SCOR) Project. *Project Completion Report.* Colombo, Sri Lanka: International Water Management Institute.

Scott, C. A., and C. Garces-Restrepo. 1999. *Conjunctive management of surface water and groundwater in the Middle Rio Lerma Basin*, IWMI-Mexico. Unpublished report.

Scott C., J.A. Zarazúa and G. Levine G. 1999. [forthcoming]. Urban wastewater reuse for crop production in the water-short Guanajuato river basin, Mexico.

Seckler, David. 1996. *The new era of water resources management: From "dry" to "wet" water savings*. Research Report 1. Colombo, Sri Lanka: International Irrigation Management Institute.

Seckler, D., U. Amarasinghe, D. Molden, R. de Silva, and R. Barker. 1998. *World Water Demand and Supply, 1990 to 2025: Scenarios and Issues*. Research Report 19. Colombo, Sri Lanka: International Water Management Institute.

Seckler, D., R. Barker, and U.A. Amarasinghe. 1999. Water scarcity in the twenty-first century. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 29-42.

Skogerboe, G.V. and D.J. Bandaragoda. 1998. *Towards environmentally sustainable agriculture in the Indus Basin Irrigation System.* Report No. R-77. Lahore, Pakistan: Pakistan National Program-International Water Management Institute.

Smedema Lambert. [forthcoming]. Irrigation-induced river salinization: A comparative study of the river salinity conditions in five major irrigated basins in the arid zone. Colombo, Sri Lanka: International Water Management Institute.

Starkloff, R., D.J. Bandaragoda, M.A. Cheema, and M.A.Bhatti. 1999. Social organization for improved system management and sustainable irrigated agriculture in small dams. *Final report of an action-research program*, IMWI–Pakistan.

Strosser, P. 1997. *Analyzing alternative policy instruments for the irrigation sector: An assessment of the potential for water market development in the Chistian sub-division*. Ph.D. Dissertation. Wageningen Agricultural University, Netherlands.

SWIM. 1999. *Final Report for start-up phase: A report to donors*. Colombo, Sri Lanka: International Water Management Institute.

TAC Secretariat. 1994. Report of the first external program and management review of the International Irrigation Management Institute (IIMI). CGIAR Secretariat. Rome: FAO.

Thiruvengadachari, S., and R. Sakthivadivel, 1997. *Satellite Remote Sensing Techniques to Aid Irrigation System Performance Assessment: A Case Study in India*. Research Report 9. Colombo, Sri Lanka: International Water Management Institute.

van der Hoek, W., F. Konradsen, D.S. Dijkstra, P.H. Amerasinghe, F.P. Amerasinghe. 1998. Risk factors for malaria: A microepidemiological study in a village in Sri Lanka. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 92: 265-269.

van der Hoek, W., F. Konradsen, K. Atukorala, and T. Wanigadewa. 1998. Pesticide poisoning: A major health problem in Sri Lanka. *Social Science and Medicine*. 46: 495-504.

van der Hoek, W., F. Konradsen, W.A. Jehangir WA. 1999. Domestic use of irrigation water: health hazard or opportunity? *International Journal of Water Resources Development*, [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 107-119.

Vander Velde, E. J.; and D.H. Murray-Rust. 1992. Impacts of physical managerial interventions on canal performance in Pakistan: A review of five years of field research studies. *Paper presented at the Eighth Internal Program Review*. IIMI. Colombo.

Van Koppen, Barbara. 1999a. Targeting irrigation support to poor women and men. *International Journal of Water Resources Development*. [Special Double Issue:

Research from the International Water Management Institute (IWMI)]. Vol. 15 (1&2): 121-140.

Van Koppen, Barbara. 1999b. *Sharing the last drop: water scarcity, irrigation, and gendered poverty eradication.* Gatekeeper Series no. 85. International Institute for Environment and Development. Sustainable Agriculture and Rural Livelihoods Programme. London: International Institute for Environment and Development.

Van Koppen, Barbara. 1999c. *Irrigation Management Transfer in the Arabie/Olifants Scheme. Summary Findings of an Appraisal*. Unpublished mission report. Colombo, Sri Lanka: International Water Management Institute.

Van Koppen, Barbara. 1999d. *More crops and jobs per drop. Managing water for gendered poverty alleviation and agricultural growth.* Colombo, Sri Lanka: International Water Management Institute.

Vehmeyer, P.W., R.R. Abbasi, M.A. Khan, A.H. Khan and G.V. Skogerboe. 1998. *Methodologies for developing downstream gauge ratings for operating canal discharge-regulating structures*. Report No. R-48. Lahore, Pakistan: Pakistan National Program-International Water Management Institute.

Vermillion, D. L. 1997. *Impacts of irrigation management transfer: A review of evidence,* Research Report 11. Colombo, Sri Lanka: International Irrigation Management Institute.

Vermillion, D. L. and C. Garces-Restrepo. 1998. *Impacts of Colombia's current irrigation management transfer program,* Research Report 25. Colombo, Sri Lanka, International Water Management Institute.

Vermillion, D. L. and D.J. Merrey. 1998. What the 21st century will demand of water management institutions. *Zeitschrift fur Bewasserungswirtschaft,* 33 (2):165-187.

Vermillion, D. L., Samad, M., Suprodjo Puspostardo, Sigit S. Arif and Saiful Rochdyanto. 1999 [forthcoming], *An assessment of the small scale irrigation management turnover program in Indonesia,* Research Report. Colombo, Sri Lanka, International Water Management Institute.

Video. [forthcoming]. *Irrigation in the Andean community: a social construction*. Ecuador. CESA, SNV, CICDA, DIGS, PEIRAV, and CAMAREN. English and French versions.

Voogt, de K., G. Kite, P. Droogers, and H. Murray-Rust. 1999. Modelling water allocation between a wetland and irrigated agriculture in the Gediz Basin, Turkey. *Water Resources Development* (submitted).

Wade, R., and R. Chambers. 1980. Managing the main system: Canal irrigation's 'blind spot'. *Economic and Political Weekly* 15 (39): A107-A112 (Review of Agriculture).

Waheed-uz-Zaman. 1998. *Impacts of farmer participation for water resources management in the Punjab Province.* Report No. R-76. Lahore, Pakistan: Pakistan National Program-International Irrigation Management Institute.

World Bank. 1994. *Pakistan Irrigation and Drainage: Issues and options.* Report No. 11884-Pak, AOD, World Bank, 25 March 1994.

Zwarteveen, Margreet Z. 1995a. Gender aspects of irrigation management: rethinking efficiency and equity. In: *Johnson, S.H., D.L. Vermillion and J.A. Sagardoy (eds). Irrigation management transfer. Selected papers from the International Conference on Irrigation Management Transfer.* September 1994. Wuhan, China. Rome: International Irrigation Management Institute and Food and Agricultural Organization of the United Nations.

Zwarteveen, Margreet Z. 1995b. *Linking women to the main canal: Gender and irrigation management*. Gatekeeper Series no. 54. International Institute for Environment and Development, Sustainable Agriculture Programme London: International Institute for Environment and Development.

Zwarteveen, Margreet Z. 1997a. *A plot of one's own: gender relations and irrigated land allocation policies in Burkina Faso*. Research Report 10. Colombo, Sri Lanka: International Irrigation Management Institute.

Zwarteveen, Margreet. Z., 1997b. Water: from basic need to commodity: A discussion on gender and water rights in the context of irrigation. *World Development*. 25(8): 1335-1349. Great Britain: Pergamon Press.

Zwarteveen M., and N. Neupane. 1996. *Free riders or victims: Women's non-participation in irrigation management in Nepal's Chattis Mauja Scheme.* Research Report 7. Colombo, Sri Lanka: International Irrigation Management Institute.