Annual Report 2000-2001

PN-ACM-412
110497

Improving Water and Land Resources Management for Food, Livelihoods and Nature

Case Studies. Impacts and Outputs. Strategic Priorities 2000-2005

IWMI
International Water Management Institute

CONTENTS

Letter from the Board Chair ... 2

Director General's Comment ... 4

IWMI's Strategy for 2000–2005 ... 8

The Year in Review: Events, Impacts and Research Results ... 10

Research Themes and Case Studies*

Integrated Water Management for Agriculture ... 14
Case Study: Water Use by Trees and Homestead Gardens in Irrigation Schemes

Sustainable Smallholder Land and Water Management Systems ... 22
Case Study: Low-cost Irrigation Technologies for Poverty Reduction

Sustainable Groundwater Management ... 30
Case Study: Using Monsoonal River Flows to Recharge Groundwater

Water Resources Institutions and Policies ... 38
Case Study: The Impact of Irrigation Management Transfer on African Smallholders

Water for Health and Environment ... 48
Case Study: Risks and Benefits of Wastewater Irrigation

Donors ... 56

Board of Governors ... 57

Financial Overview ... 58

Project Portfolio for 2001 ... 62

Institute Staff ... 66

Publications ... 68

*Case studies are derived from research papers compiled during 2000.

IWMI is on the move!

Facing the challenge of a changing environment

The demands on international research organizations are changing rapidly. Increasing capabilities of national research organizations in many large developing countries demand that organizations such as IWMI move out of their way—while remaining a reliable partner in areas where international organizations have a comparative advantage. International research centers have an edge in carrying out comparative work in sites across countries, in developing international networks and partnerships and in doing strategic, upstream policy-oriented research. At the same time, there are other countries, for example in sub-Saharan Africa, where national research budgets are under pressure and capacity building is crucial.

In all countries where IWMI works, the impact of new technologies—including remote sensing, GIS, the Internet—on the way research is carried out and cooperative research is implemented is very significant. Involvement of stakeholders in agenda setting, in research, in policy development and in implementation of policies has become given in many countries. The reorganization of the CGIAR that is currently underway demonstrates the need to adjust to this changing environment.

In addition, IWMI is faced by the challenge that 'water' is rising on many political agendas. This is happening because the scarcity of water is felt in an increasing number of countries and seen as a future threat by many others. Providing enough water to produce food, sustain rural livelihoods, healthy populations and a healthy environment is going to be a major challenge—particularly in Asia and Africa.

To address these challenges, IWMI's new Director General led a major exercise in the second half of 2000 to develop a new Strategic Plan. This process involved many of its staff members and stakeholders. The new Strategic Plan was approved by the IWMI Board in December 2000 and well received by the CGIAR's Technical Advisory Committee (TAC) in March 2001[1]. Through this new Strategic Plan—the Institue's business plan for the coming years—the Board of Governors is confident that IWMI will be ready for the challenges that it faces. IWMI is also ready to play its part in the new and reinvigorated CGIAR that will emerge from the current reorganization.

Implementing the Strategic Plan

The change in research focus over the past five years of the former IIMI[2]—with its exclusive focus on managing irrigation systems—to that of the new IWMI—has repositioned the organization considerably. Integrated water resources management at the basin level has become the Institute's core business: Extending the focus from downstream water management in irrigated agriculture to upstream concerns in catchment areas, to small-scale water management and water harvesting,

[1]The IWMI Strategic Plan 2000-2005 is available from IWMI, www.iwmi.org, and its key issues are briefly summarized in this document as well.

[2]The International Irrigation Management Institute (IIMI) changed its name to the International Water Management Institute (IWMI) in 1997.

from irrigated to rain-fed agriculture, and to interactions with other water users and the environment. Putting people first and working directly with farmers, water user organizations and water managers have always been a hallmark of IWMI—old and new.

In light of this shift in the research domain, a further extension towards water and land management comes naturally. The management of water and land resources, and water and land use planning and management, are closely intertwined and need to be looked at together. This focus is reflected in the new IWMI mission adopted in Strategic Plan 2000-2005 as:

improving water and land resources management for food, livelihoods and nature

The integration of the program of the former IBSRAM[3] into IWMI sharpens the focus on land use issues in IWMI's predominantly water-oriented research agenda. Smallholder land and water systems is one of the five cross-cutting IWMI research themes into which the majority of IBSRAM's programs are merged. Another new research theme for the Institute is sustainable groundwater management, which is being done vigorously through a series of research activities, particularly in India, Pakistan and China. Increased research on the agriculture-environment interface is also emerging.

Work in Africa is expanding rapidly through the new regional office for Africa in Pretoria, and an office of the former IBSRAM in Ghana. Where IWMI had only one internationally recruited researcher resident in Africa in mid-2000, this will climb to ten before the end of 2001. With another regional office opening in India early in 2001, it is expected that by the end of 2001 more than half of IWMI's researchers will work outside headquarters in Sri Lanka, particularly in the regional offices in South Africa, Pakistan, India and Thailand.

This will be largely due to a very considerable expansion in research capacity during 2001. Recruitment of about seven former IBSRAM researchers is part of this, but a larger part is a drive to recruit young researchers (mostly internationally recruited PostDocs) from the South. IWMI expects to have appointed 15 new PostDocs and Associate Experts before the end of 2001.

I quote these numbers to demonstrate that 'IWMI is on the move'. The refocusing of the research agenda over the past five years has put the Institute in a good position to move forward rapidly to address the challenges that face international research organizations today—particularly, the improved management of water and land resources. IWMI is ready to contribute to increased food security for all, better livelihoods for the rural poor and to a healthy natural environment.

Prof. Klaas Jan Beek
Chairman of the Board of Governors

[3]The International Board for Soil Research and Management (IBSRAM) had transformed itself into an international organization focusing on sustainable land management through research networks in Asia and Africa. No longer independently viable, IBSRAM wound down its operations and transferred its programs to IWMI, effective 1 April 2001.

Genomics and Water Management?

Water for agriculture gets squeezed-poor farmers first

As populations rise, incomes rise, and countries industrialize—the demand for water in urban areas in developing countries will rise very strongly in the coming decades. At the same time increased environmental awareness will place more and more emphasis on maintaining a healthy environment for people and for nature. The large-scale development of river and groundwater resources is less acceptable now than it was in the1960-1990 period, when the large majority of the world's 45,000 large dams was built. Additionally, water infrastructure built in recent decades is becoming obsolete—for example through silting up of reservoirs, and crumbling irrigation networks—and there appears to be a decreasing willingness to fund rehabilitation and replacement of this infrastructure. Groundwater levels are falling in key aquifers that have contributed substantially to food security in recent years through provision of water-on-demand to millions of farmers who tapped them directly through tube wells. In all these developments, as resources become more scarce, the poor and vulnerable are hit first and suffer the most.

Water for agriculture is being squeezed as this resource is moved out of the farming sector and diverted to urban areas. Groundwater sources are drying up, and the willingness to develop new resources has declined for financial as well as environmental reasons. The consequences of this situation are visible, for instance, in Pakistan, home to the world's largest irrigation system and today, to increasingly serious droughts. Agriculture has grown used to cheap and plentiful water in irrigated areas. As the human population tripled in the 20th century, water use multiplied sixfold, mostly for agriculture. Agricultural productivity has risen sharply in recent decades due to higher-yielding crop varieties and increased fertilizer use. This increase was also due to major investments in water resources infrastructure and to massive energy subsidies for pumping groundwater, that are less likely to be repeated in the coming decades.

Against this background, the question appears to be: **How will we find sufficient water to provide food security, health and livelihoods to a growing world population— in harmony with other water users and the environment?** This is truly a global challenge, that should perhaps be reformulated as follows:

How can we grow the food we need with the water available?

To grow enough food and provide sustainable livelihoods to poor people with the available water will require a considerable overhaul of the way agriculture is practiced. The dominant

agricultural philosophy that views land as the scarce resource and aims to maximize crop yields per unit of land through better varieties—while removing nutrients and water as constraints[1]—needs to be replaced. It should be replaced by a philosophy that views land, water, nutrients and genetic resources as an integrated set of scarce resources that need to be managed by the stakeholders.[2]

For water and land resources management there are three priorities:

1. To implement better water and land resources management practices in agriculture, forestry and fisheries.
2. To increase the understanding between agriculture and other water users, particularly environmental uses.
3. To reduce agriculture's water use and dependence.

We are proposing major initiatives, involving the CGIAR in a central role, to address these priorities.

Comprehensive assessment of water management in agriculture

There are many ways in which water can be managed better, ranging from better technology such as laser-land-leveling or drip irrigation to better involvement of users in planning and management of resources. Collectively these are known as 'integrated water resources management' and most of IWMI's work deals with specific aspects of this. Particularly in upper catchment areas and on hillsides, but not limited to these areas, better water management should to be intertwined with better land management, for example through integrated watershed or catchment management approaches.

While it is clear that water and land resources management in currently cultivated systems can be improved, it is not clear by how much irrigated areas should be expanded in the coming decades. Irrigated agriculture—'old style', large-scale publicly funded irrigation systems—has gained an ambiguous reputation with parts of society. The willingness to invest in new systems has declined. Others, particularly in the irrigation and drainage community, hold it self-evident that considerable expansion of irrigated areas is necessary and unavoidable to achieve food security and reduce hunger and poverty in rural areas.

IWMI has initiated a major research program to assess the benefits and costs of the investments in water management for agriculture in the past and to assess future options.[3]

---

[1]Achieved through higher-yielding varieties, cheap fertilizer and essentially free water.

[2]This is, of course, nothing more or less than a plea for integrated natural resources management.

[3]The *Comprehensive Assessment of Water Management in Agriculture,* reformed from the former System-Wide Initiative on Water Management (SWIM) and therefore also referred to as SWIM-2.

This program is designed to involve CGIAR institutes and other partners in an international effort to provide credible and authoritative knowledge—international public goods—to the agriculture and environment communities. This research is embedded in a wider program that will foster dialogue among the agricultural and environment communities, particularly, at national and basin levels.

Dialogue on Water, Food and Environment

Bridging the gaps in perception on the desirable directions in water management for agriculture will reduce conflicts among users and increase the resources available for broadly supported investments. To this end, a broad consortium is being established that will catalyze a process of cross-sectoral *dialogue on water for food and environmental security*.[4] IWMI has taken the initiative for this exercise and will host the Dialogue Secretariat. A sponsor group chaired by the Netherlands government has been established to support the exercise. Significant resources from outside the CGIAR are expected to be available for the program and its components such as the Comprehensive Assessment. The Dialogue will be formally launched in August 2001 at the Stockholm Water Symposium.

The global challenge for water and agriculture

But there is a broader global challenge that goes considerably beyond the implementation of improved water and land management practices in agriculture, forestry and fisheries. That is the challenge of addressing water and land resources management practices in conjunction with (1) breeding plants that are more drought-resistant and have a higher yield per unit of water and (2) the management of soil fertility.

The CGIAR system is uniquely positioned to address this challenge. The crop centers combine the expertise to address drought resistance and water productivity—even though concentrating on these multiple traits will mean a relative shift in focus. It will require a considerable paradigm shift to think in terms of *yield per unit of water* as a significant complement to *yield per unit of land*. Key areas of a major research programe that addresses this water and agriculture challenge, to be addressed in a coordinated framework, can be grouped as follows:

1. Increasing the drought-stress tolerance of key irrigated and rain-fed food and cash crops through breeding and biotechnology, thereby adapting agriculture to increased climatic variability due to anthropogenic climate change.
2. Increasing the water productivity of key food and cash crops through breeding and biotechnology.

[4]Initially consisting of the Food and Agriculture Organization (FAO); Global Water Partnership (GWP); International Commisison on Irrigation and Drainage (ICID); IUCN, The World Conservation Union; International Water Management Institute (IWMI); United Nations Environment Programme (UNEP); World Health Organization (WHO); and World Water Council (WWC).

3. Improving soil water and soil fertility management to sustainably increase crop yields, particularly in rain-fed agriculture.
4. Improving integrated water resources management at the basin level to increase water productivity and (re-)allocate water resources to a sustainable mix of high-value uses, from crops to forestry, to fisheries, the environment and domestic and industrial use, and reduce conflicts among users.
5. Integrated natural resources management with full involvement of all stakeholders and explicit sustainability and poverty alleviation objectives.

The potential of genomics for water and agriculture

The overall objective of the global challenge program on water and agriculture could be to sustainably increase global food production by 40% while reducing the renewable water resources used in agriculture by 10–20% in the next 25 years. This would imply a reduced use of water for agriculture over current projections by some 600-700 cubic kilometers—of the same order as the additional water required for domestic and industrial purposes.

Improved water resources management practices by themselves are unlikely to achieve this goal. In fact, the largest potential for a breakthrough may come from the advances in genomics that allow the manipulation of the multiple genes that govern drought-tolerance and water productivity in plants.

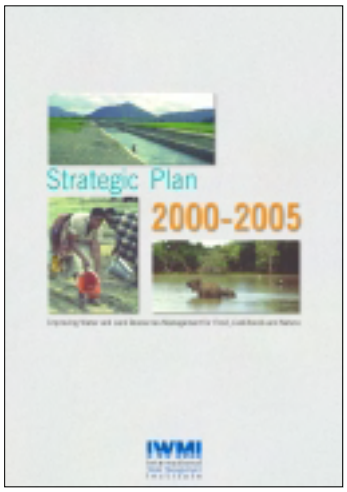
Frank Rijsberman
Director General

IWMI's road map to 2005

The IWMI Strategy 2000-2005 is our road map, which guides the Institue's research agenda for the next five years. It identifies the problems that need to be solved related to water, poverty and rural development; chooses the areas where we are confident we can make a contribution-an impact that grows out of research findings-and explains how we will organize ourselves to deliver on this commitment.

The strategic plan was developed over a six-month period in a series of brainstorming sessions between IWMI staff and partners. The drafting was facilitated by a task force led by the Director General. This process included open consultations, and input on three drafts, from some 70 IWMI colleagues and stakeholders worldwide-from the donor, research and national partner communities.

Out of these discussions grew a series of facts and conclusions about how the Institute can best move forward. Some examples are:



- **The Institute has expertise in certain areas that can be capitalized on.** Two new research themes were formed to bring out specific areas of excellence that were "hidden" in general research activities. The Institute decided to create specific research themes for smallholder water and land innovations and sustainable groundwater questions.

- **More research "firepower" is needed to tackle a broader research agenda.** A post doctoral program was started, and a first group of young professionals joined the Institute in January 2001. Through this program IWMI will increase its research ranks by up to 50 researchers over five years. This will also dramatically increase the number of young scientists from the South at the Institute.

- **Research goals are quantifiable and impact-oriented. The Institute has a wealth of research that will be more aggressively disseminated and put into the hands of users.** The new work plans that guide each of IWMI's five research themes are as specific as possible about the type of outputs (in terms of types of tools and practical materials to be delivered) and impact (in terms of people affected). A series of strategic partnerships have been signed with national agencies, international NGOs with broad local links and research institutes with complementary expertise. The goal of these partnerships is to bring research results to users.

Setting Strategic Priorities: Five Research Themes

The continuity of IWMI's research and its strategic priorities over the coming five years will be driven by five Research Themes:

- Integrated Water Management for Agriculture
- Sustainable Smallholder Land and Water Management Systems
- Sustainable Groundwater Management
- Water Resources Institutions and Policies
- Water for Health and the Environment

The Themes are ***five interconnected research missions*** for IWMI. The work of each Theme is guided by an action plan and specific targets to be attained.

A series of Benchmark River Basins complements the work of the Research Themes. These are IWMI's 'field laboratories', where water management tools and concepts are tested in real-life situations, and data is gathered on an ongoing basis.

A further impact of this activity is the long-term partnerships that IWMI will forge with local universities, research institutes, national authorities and others in the countries where Benchmark Basins are located. Benchmark sites are being established in Sri Lanka, Pakistan and Southern Africa in 2001. By 2005 there will be some 10-12 such Basins across Asia and Africa.

Research Themes:

Integrated Water Management for Agriculture

Understanding irrigation in its true context. From field to river basin, looking at the needs of farms, communities, and nature.

This research theme brings together much of the core of the Institute's expertise, knowledge base and research outputs that have been produced over the past five years. Over the coming five years, this research will be deepened-concentrating on the areas of irrigation management, river basin analysis and global-scale strategic analysis of water resources.

A key focus of all research under this theme will be to look at irrigation management from the perspective of the competing uses of water in river basins, including agriculture, nature, local communities, cities, industry, etc.

Research Themes	Regional Offices				
	Sri Lanka (Asia including China)	Thailand (Southeast Asia)	Pakistan (Central Asia/ Middle East)	South Africa (Africa)	India
Integrated Water Management for Agriculture					
Sustainable Smallholder Water and Land Management Systems					
Sustainable Groundwater Management					
Water Resources Institutions and Policies					
Water, Health and Environment					

Sustainable Smallholder Land and Water Management Systems

Identifying and evaluating water and land use innovations developed by poor communities. Promoting their transfer to benefit people in other areas.

Across Asia and Africa many villages and poor communities have developed novel approaches for handling scarce water and land resources. This research theme concentrates on identifying these promising innovations and evaluating them to understand why they work. Examples include, treadle pumps, bucket and drip irrigation technologies, and water-harvesting initiatives.

Sustainable Groundwater Management

Providing a more precise understanding of the socio-ecological problems surrounding groundwater. Aggressively promoting solutions for its sustainable use in developing countries.

The goal of IWMI's groundwater research is to help countries, regions and local communities achieve sustainable use and management of groundwater, in ways that promote food and livelihood security for the poor women and men in Asia and Africa.

Activities include: assessing the extent of groundwater use for irrigation; exploring groundwater mapping techniques; understanding the factors contributing to overdraft and contamination; and evaluating groundwater recharge practices at the village and regional level.

A series of groundwater research products will grow out of this research, including research publications, models, analytical tools and policy papers aimed at encouraging policy makers to take action.

The final step is to study how these practices can be adapted and transferred to help improve the livelihoods of the poor in other countries. The end result of this research is tools, concepts and 'appropriate technologies' that help poor people farm small landholdings more profitably and sustainably.

Water Resources Institutions and Policies

Studying and proposing 'best institutional and policy practice' for water management in developing countries. Creating a lasting network of institutional policy research groups to drive change.

This research theme examines how communities, governments and society deal with problems of water resources management. It involves the study of legal aspects, policies and institutional arrangements-from the rural communities to regional and national levels. The goal of this work is to produce guidelines and best practices that can help policy makers better manage their countries' water resources.

The work covers the institutional and policy implications of:

- Strategies for enhancing the productivity of water (at national, basin and local levels).
- Building poverty and gender concerns into national and subnational water management regimes.
- Managing water scarcity and its consequences.
- Farmer-led participatory irrigation management and irrigation management transfer.

Water Health and Environment

Putting health and environmental issues on the water management agenda. Creating tools to better address the health and environmental aspects of water in agriculture.

This research aims to improve the lives of poor people in agricultural areas by gaining a better understanding of the interactions between water use in agriculture, human health and environmental needs.

Health. The health component of this research includes studying changes in the operation and design of irrigation systems that could reduce snail and mosquito vector populations to prevent malaria, Japanese encephalitis and schistosomiasis. Research also examines the health impacts of common practices such as the domestic use of irrigation water and the use of untreated wastewater to irrigate crops. The goal is to find ways of maximizing the positive benefits of these practices while minimizing the health risks.

Environment. IWMI's water and environment research attempts to bridge the gap between irrigation and the environment (nature conservation) sectors. A large part of this work involves documenting the relationship between water used for agriculture and the needs of natural ecosystems, and the competition between these two sectors. Through this work, IWMI is developing practical ways to quantify and manage irrigation water and drainage flows in ways that sustain ecosystems while obtaining optimum agricultural production.

Fighting Malaria with Better Agricultural Practice

What are the links between agriculture and the spread of malaria? How can agricultural-based interventions reduce malaria in rural areas?

The Systemwide Initiative on Malaria and Agriculture (SIMA), focuses the combined skills and abilities of the agricultural research community, government agencies, malaria programs, and non governmental and community-based organizations, on the problem of malaria in agricultural areas.

For the past two decades, chemical, pesticides and drugs have been the weapons of choice in the battle against malaria. But as mosquitoes are becoming more resistant to pesticides and many drugs are losing their effectiveness against the malaria parasite, communities affected by this disease are ready for new approaches-ones that are cost-effective and don't involve harmful pesticides. Agricultural-based interventions offer new hope.

While malaria has well-known environmental determinants-specifically its links to water-little research has been done that examines the links between water use in agriculture and the 350 million annual cases of malaria in Asia and Africa. A better understanding of these links is the first step towards finding innovative solutions. Under SIMA, research will study water and land practices across a range of crops and ecosystems in Africa to determine the farming activities that encourage, and discourage, the breeding of malaria vector mosquitoes. Based on this research, guidelines and tools will be developed and tested for use in community-based efforts and NGO and government initiatives.

IWMI, as the lead institute of the initiative, hosted an exploratory meeting in Colombo in December of 2000. An electronic discussion has been launched to stimulate the exchange of ideas between interested potential partners. A key stakeholders' meeting was held in Niarobi, Kenya to pool available knowledge and shape the research agenda.

For documentation and full details, point your browser to: www.iwmi.org/sima

A New Regional Office in South Africa

There is now widespread agreement that in much of Africa, making water available to rural poor people for both productive and domestic uses is a key opportunity for reducing poverty and improving people's lives. IWMI's study of global water scarcity shows that at a national level, nearly all African countries are either water-scarce or lack the financial resources needed to develop sufficient water resources to meet projected needs. Analysis on a smaller scale reveals that even in countries which seem to have enough water, there are pockets of scarcity and acute shortages.

To further strengthen its work in Africa, IWMI opened a new Africa Regional Office in Pretoria, South Africa in November 2000. This regional office coordinates IWMI's research activities in southern and sub-Saharan Africa, and provides support to three smaller sub regional offices in Ghana, Kenya and Cote d'Ivoire. The IWMI scientific team based in the region-expected to grow to 20 professional staff in the next five years-includes specialists in areas such as hydrology, agriculture, sociology, economics and gender.

Primary research activities in Africa include:

- work with regional and international partners to identify long-term opportunities and limitations for enhancing food security and economic development, while conserving soil and water resources.

- applied research to find viable technologies, practices, institutions and policies that will lead to immediate gains in food security and incomes for poor men and women in rural areas.

- dialogues with policy makers and stakeholders to help them incorporate best practices into their agricultural and water management planning.

- capacity building through: financial and intellectual support to MSc. and Ph.D. students, the recruitment of postdoctoral researchers, curriculum development with universities and training programs.

To accomplish this work, IWMI will tap the expertise of researchers and technical experts from a number of African universities. The Institute is also working with governments and local and international NGOs to ensure that research results reach end users. IWMI's participation in the Southern African Regional Irrigation Association (SARIA) is a good example of the kind of collaboration the Institute hopes to encourage through its work in the region. IWMI is a founder member of the Association, which was launched in October 2000 to overcome the lack of interaction between irrigation professionals, farmers and officials in the region.

IWMI's research program for the region builds on more than a decade of work in the region. This research has focused on areas such as catchment management at the national, regional and international scales; small-scale community irrigation and transfer of former government-run irrigation schemes to farmers; water harvesting, groundwater and smallholder precision irrigation; and the health impacts of agricultural expansion, including malaria, schistosomiasis and nutrition.

How much water do we need for food production and nature?

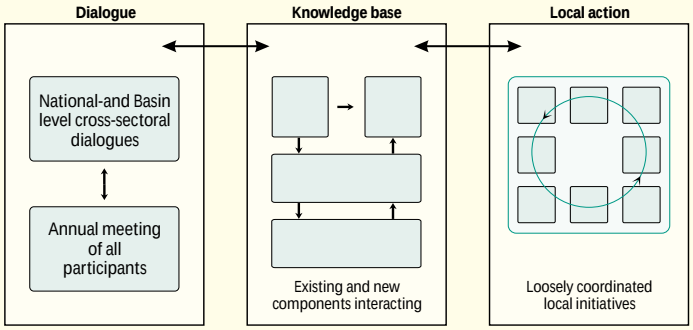
Dialogue on Water, Food and Environment

IWMI is a founder member and a catalyst behind the creation of the Dialogue on Water, Food and Environment. This is an important new research initiative that brings together the agriculture and environment communities. The objective of this initiative is to arrive at a knowledge-based consensus between these two communities, on the present and future needs of water for food production, livelihoods, health and nature in developing countries.

The current partners in this initiative are: Food and Agriculture Organization (FAO); Global Water Partnership (GWP); International Commission on Irrigation & Drainage (ICID); World Conservation Union (IUCN); International Water Management Institute (IWMI); United Nations Environmental Programme (UNEP); World Health Organization (WHO); and World Water Council (WWC).

The process started in December 2000 when over 130 stakeholders from around the world came to a planning and design meeting in Colombo to help shape the Dialogue initiative. An agenda with points for action has been agreed on between all partners, and the group is now planning for specific action. A Consortium was formed at a meeting in March 2001 at the FAO. A Dialogue secretariat is planned to be hosted by IWMI, and IWMI Director General Frank Rijsberman was elected the first chair of the Consortium.

For papers, discussions and full details, point your browser to: www.iwmi.org/dialogue



Comprehensive Assessment of Water Management in Agriculture: Costs, Benefits and Future Directions

The Dialogue acts at the policy level and will be fed with information from a *Knowledge Base* drawn from research done by experts on relevant topics- centered around water use in agriculture and environmental/ecosystem management.

IWMI's knowledge base contribution is a major international research initiative- the *Comprehensive Assessment of Water Management in Agriculture: Costs, Benefits and Future Directions.* This assessment will look at the global situation of water management for agriculture since 1950 to the present. It will conduct studies in a number of ecosystems where there is likely to be a competition between the need to expand food production and maintain local wetlands and other natural systems.

IWMI's work on the Comprehensive Assessment is a continuation from the CGIAR Systemwide Initiative on Water Management (SWIM)- and is also referred to as SWIM-2.

For full details, point your browser to: www.iwmi.org/assessment

IWMI Integrates IBSRAM's Sustainable Land Management Research

IMWI has added sustainable land management expertise to its research portfolio, with the integration of the research program of IBSRAM-the International Board for Soil Research and Management-into the IWMI research themes.

The integration of the 15 years of land management research, tools, and extension networks across Asia, strengthens IWMI as a natural resources research center and brings new skills and useful knowledge into the CG System.

The networks bring with them a range of new partners' which extend the Institute's reach and provide new sources of data and experiences that are fed into the IWMI research themes.

- The **Catchment management network** is a consortium for research on catchement management, composed of stakeholders in water catchments- in Indonesia, Laos, Malaysia, Nepal, Philippines, Thailand, and Vietnam, together with 20 national partners, and three advanced research organizations.
- **Soil conservation on sloping lands** is a seven-country network (China, Indonesia, Laos, Malaysia, Philippines, Thailand, and Vietnam) which brings together researchers' and farmers. Research findings are being introduced on a large scale through demonstration and extension programs.
- The network for **acid and infertile soil management**, seeks ways to better manage acid and infertile soils, with particular attention to phosphorus management- in Indonesia, Myanmar, Philippines and Vietnam.
- **Nutrient recycling in urban and peri-urban areas**- a regional consortium for research and capacity building.

Other research being integrated into IWMI is: projects to determine nutrient balances of farms on marginal lands; providing practical land management information for farmers and their children through the Internet (Indonesia, the Philippines, and Thailand); and a training program on land and water legislation to give NARES examples of best practice from which they can build their policies.

5-Basin Study

Meeting the challenges faced by water-sector institutions

In five river basins in Asia, IWMI researchers have been studying how water-sector institutions can more effectively deal with the growing problems of water scarcity and inter-sectoral competition for water. This research is creating a better understanding of the problems in water-short basins, and documenting how these countries are addressing them. The basins studied are the Fuyang (North China), East Rapti (Nepal), Lembang/Sumpur/Ombilin (Indonesia), Pampanga (the Philippines) and Deduru Oya (Sri Lanka). In-depth field studies, which were completed in 2000, included analysis of: physical characteristics, water accounting, socioeconomic conditions and performance assessment of the selected basins. An important goal of this work is to is to encourage policy makers and water planners to look at their water situations from a new perspective-that of the river basin."We are working to better understand what policies are in place in each country to ensure the water needs of its poor people, and analyzing which approaches work and why," says Tissa Bandaragoda, the IWMI researcher leading this project. *Funding is provided by the Asian Development Bank.*

IWMI-IUCN Cooperation

How does irrigation development impact natural ecosystems?

One perceived impact of large-scale agricultural development is the harm caused to local plant and animal species, and the disruption of food chains and webs that maintain the ecological balance. Unfortunately, scientific assessments of the ecological impacts of agricultural expansion are generally based on limited knowledge of the ecosystem's original state. The Uda Walawe Irrigation Extension Development Project in Sri Lanka has provided IWMI researchers with a rare opportunity to assess biodiversity before and after irrigation development. IWMI scientists, in collaboration with IUCN Sri Lanka, have begun taking an inventory of plant and animal species within the area to be developed. One outcome of this initial stage of the study, will be the identification of habitat types and natural resources zones within the extension area whose conservation could particularly benefit stakeholders.

Tools and Concepts for Improved Water Management

IWMI's tools for water resources management have been developed and validated through research done over the past six years. These tools provide data, methods and practices useful to water managers and food security planners in developing countries, and the development and agricultural research community.

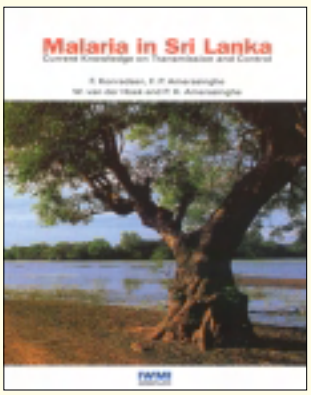
The final version of the **World Water and Climate Atlas**, compiling 30 years of climate data for 130 countries, is now complete. Over 500 CDs were distributed during the last quarter of 2000 and some 600 copies were downloaded from the institute's web site. A rapid query service which delivers Atlas data to users on-line is also now available. *Funded by Official Development Assistance, Japan and the United States Agency for International Development.*

Research on **practical, low-cost remote-sensing tools** for water management is now being developed into a Users Manual, with the goal of encouraging as many developing countries as possible to make use of this research.

The IWMI **Water Accounting System** was applied in ten river basins. This tool, which encourages an integrated approach to water management, has provided input on the multiple uses of water to discussions on the role and responsibilities of river basin institutions.

The IWMI **Policy Dialogue Model, PODIUM**, was used to explore potential impacts of the water and food security scenarios developed for the Second World Water Forum (2000). It was also used to generate discussion in the eight regional dialogues held as part of the Vision 2025 excercise.

IWMI researchers are currently working on testing and refining **a gender performance indicator for irrigation**. This useful, generic gender mapping and equity tool helps to measure poor women's equitable access to water for farming and other basic needs. Early versions of the indicator have been presented in national policy workshops in South Africa, and international conferences. The indicator has provided direct input to South Africa's gender policy on the revitalization of smallholder irrigation. *Funded by the Swedish International Development Cooperation Agency (SIDA).*



Reviewing a century of water-malaria research in Sri Lanka

It is now generally accepted that for malaria control measures to be effective, they must be based on knowledge of the local situation. A new book, *Malaria in Sri Lanka*, identifies the current state of knowledge-encompassing 100 years of malaria research and experience in Sri Lanka. The book brings together IWMI research findings and the work of Sri Lankan and international researchers. This knowledge can form the basis for adaptation of the global malaria-control strategy to the Sri Lankan situation. Although epidemiological and transmission patterns vary greatly from one country to the next, the book, which documents the successes and failures of control efforts in Sri Lanka, will also be of interest to the international community engaged in research on and control of malaria. *This book is a product of IWMI's Health and Environment research, funded by the Governments of Japan and Denmark.*

Focusing Research on the Most Water-Scarce areas

Interview with Vilma Hornikova, Director, IWMI Regional Office for Pakistan, Central Asia and Middle East.

Are there common water resources problems across the region covered by your office?

Yes. All these countries are faced with an alarming level of water scarcity. Each of them is having increasing difficulty meeting its population's water needs-for agriculture, domestic uses and other vital activities, such as fishing, river navigation and hydropower.

This chronic lack of water creates a host of problems that IWMI research is addressing. These include soil saliniztion, waterlogging, groundwater overdraft, and the health and environmental impacts of irrigating with wastewater. The knowledge generated through our research is helping the affected countries scrutinize their policies and improve organizational arrangements for managing water resources more sustainably.

Our priority for this region is to forge closer partnerships with National Agricultural Research and Extension Services (NARES). This will give us a better understanding of the specific needs of each country where we work and transfer knowledge and expertise to local communities.

IWMI's research activities are growing in Central Asia; what are the pressing water problems on which research needs to focus here?

Many issues need attention in this region, among them: institutional deficiencies, such as laws, rules and regulations; the absence of water management strategies and planning; and environmental crises, such as the severe ecological deterioration in the Aral Sea basin-due to saline irrigation water. Our research is helping to address these problems through practical guidelines and tools for governments, irrigation organizations and farmers. These help determine how much water is available to them, and see ways of changing irrigation management practices and organizational arrangements for more sustainable water use.

Our Central Asian research-coordinated from a new Tashkent office-focuses partially on the Ferghana Valley-a water-stressed area at the intersection of Uzbekistan, Kyrgyzstan and Tajikistan-that was traditionally home to the most productive and fertile lands in the region. Here we are assessing water productivity and how to use satellite remote sensing and geographical information systems to improve water management. The region also presents us with a unique opportunity to work on institutional arrangements and required changes for optimal water management across national boundaries.

NEW OPPORTUNITIES FOR Young Researchers from Asia and Africa

IWMI has launched a new program for postdoctoral researchers, with two goals: to strengthen its research expertise and to include in the Institute's ranks more young scientists from the South. The first wave of new researchers was hired in late 2000.

Dr. Jinxia Wang (China), Agricultural Economics, Chinese Academy of Agricultural Sciences.

Dr. Abdul B. Kamara (Sierra Leone), Agricultural Economics, University of Geottingen, Germany. He will be based in South Africa.

Dr. Mohammed Mainuddin (Bangladesh), Water Engineering & Management. He will be based in Pakistan.

Dr. Madhusudan Bhattarai (Nepal), Applied Economics, Clemson University, USA.

Dr. Shrinivas Badiger (India), Soil and Water Resources Engineering, University of Illinois, USA.

Two more waves of recruitment will be held in 2001. The target is to recruit 30 post doctoral fellows in the next five years.

New India Office and Policy Research Program

IWMI-Tata water resources policy research program

The year ended with the signing of a $1 million grant from Sir Ratan Tata's Trust for the launch of the IWMI-Tata Water Resources Management Policy Research Program in India. This research will raise the importance in policy makers minds of making water resources management a strategic priority, across India. Acting as a catalyst to drive this process, IWMI is bringing together a coalition of Indian institutes that have completed important research on water resources over the past 10 years. The goal is to help them translate this technical knowledge into policy tools that policy makers will understand-and make use of. 100% of this grant is earmarked for Indian partners; IWMI core funding and contributions from donors will cover IWMI research costs and follow-on activities. This program is coordinated by IWMI Principal Researcher, Tushaar Shah, from the research office in Anand Gujarat. It will be staffed by some 10 young Indian researchers (economists, hydrologists, social scientists, engineers), who will link with their colleagues in the other IWMI offices.

New regional office for India

The Institute has opened a new regional office for India, to bring the five IWMI research themes closer to the country's water resources problems. The office will be located in the complex of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad. Further development of IWMI's research in India will be done through partnerships with the Indian Council of Agricultural Research (ICAR).

Integrated Water Management for Agriculture

Developing tools, processes and knowledge to help water resources managers respond to changing needs and expectations.

Identifying and promoting sustainable options for increasing water productivity and reducing poverty

Strengthening the research capacity of partners to achieve sustainable improvements in water productivity in agriculture.

Research Themes:

Integrated Water Management for Agriculture • Sustainable Smallholder Land & Water Management Systems
Sustainable Groundwater Management • Water Resources Institutions & Policies • Water, Health & Environment

Impacts of water consumption by perennial vegetation in irrigated areas of the humid tropics

A case for rethinking traditional views of irrigation design, management and performance assessment

Daniel Renault, Manju Hemakumara, David Molden

Summary

Water developed primarily for irrigation tends to find many uses beyond the supply of water to crops. In irrigated areas of the humid tropics, water diverted for crop production supplies homestead gardens and other beneficial perennial vegetation, primarily trees, growing naturally within the command area. However, the degree of water use by this vegetation and the benefits derived from it are not well understood and is rarely taken into account in irrigation management.

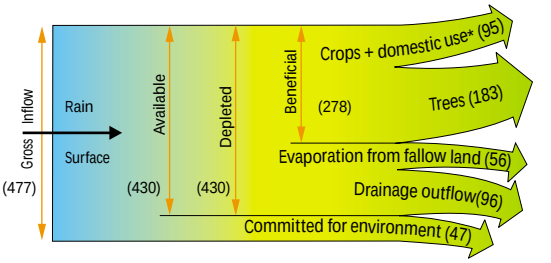
In 1998, IWMI performed a comprehensive water balance study in the command area of Sri Lanka's Kirindi Oya Irrigation Scheme to assess the impact of water consumption by perennial vegetation. The study found that perennial vegetation consumes almost twice the amount of water as crops in the area. The main conclusion from this study is that water consumption by perennial vegetation should be a significant consideration in tropical humid environments in irrigation planning, management and performance assessment.

Irrigation in tropical regions often provides benefits far beyond crop production (Bakker et al. 1999). In the dry zone of Sri Lanka, irrigation has dramatically changed the local environment, enabling ecosystems quite similar to those of the wet zone to flourish. In these irrigation systems, recharge of shallow groundwater by percolation from irrigated fields, canals, and tanks has provided a continuous supply of water for beneficial natural vegetation and homestead gardens.

In 1998, IWMI performed a comprehensive water balance study in the command area of the Kirindi Oya irrigation scheme, which is located in Sri Lanka's dry zone, to assess the water use by non-crop vegetation. The assessment was based on surface flow measurements, rainfall data and estimation of crop water requirements. This water balance showed that perennial vegetation consumed 43 percent of the water available; crops consumed only 22 percent.

It is not surprising that perennial vegetation can consume such a large proportion of the total amount of water made available in a given irrigated area. What is surprising is that little consideration has been given to this consumption. The efforts of water managers and farmers have been focused primarily on the delivery of water to crops, with little or no recognition of non-crop water use. With increasing water scarcity, more focus is being placed on the overall water balance of irrigated areas. In this context, other types of consumption besides crop consumptive use become more important.

Diagram representing the water balance in Kirindi Oya. Values shown are in million cubic meters.

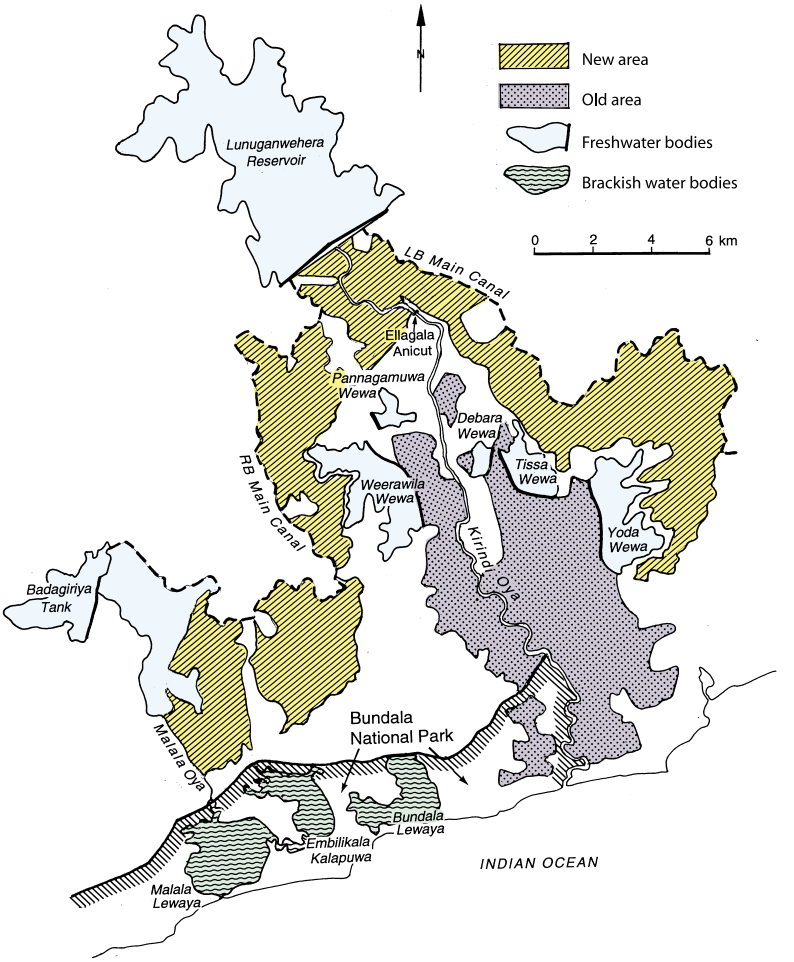


Profile of the Kirindi Oya Irrigation Scheme

The Kirindi Oya scheme is located in the dry zone of Sri Lanka. Average annual rainfall is 1,000 mm, 70 percent of which falls in a three-month period. The dry season (*yala* season) is from April to October. Minimum average temperatures vary from 26 °C in December to 28 °C in April. Values of reference evapotranspiration vary from 110 mm in November to 184 mm in August, with an annual value of 1,765 mm. During the dry season, reference evapotranspiration less rainfall is about 700 mm, indicating that much additional water is needed to support crops, mainly paddy.

In the scheme, perennial vegetation has developed over time and now covers a great part of the area. It must be stressed that the importance of perennial vegetation is the result of paddy cultivation. Other crops and other irrigation techniques at the field level would have led to a completely different picture. A survey made during the yala season in 1998 has shown that, on average, groundwater depth in the older part of the Kirindi Oya scheme, the Ellegala system, varies from 1.6 m to 2.8 m below the surface. Tree roots can readily tap groundwater at this depth even in the dry season.

Map of Kirindi Oya Irrigation System showing both the older and the newly developed areas.



Vegetative coverage in the Old System (EIS) is much more than in the New System (NIS) for three main reasons:

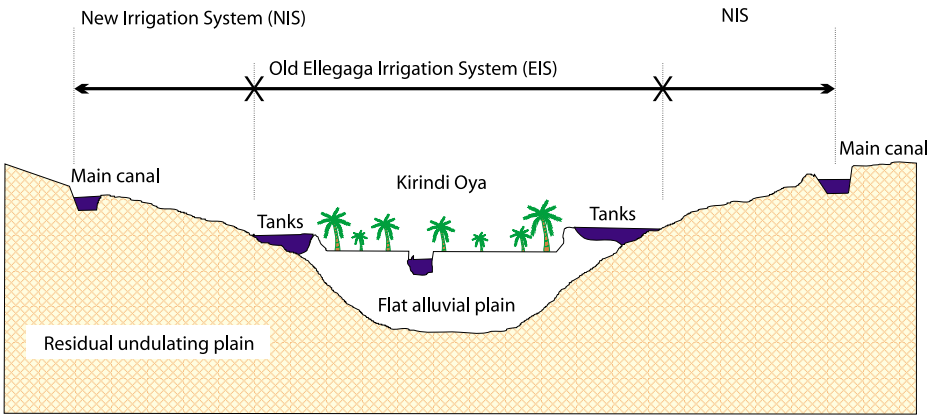
- Historical—the old system has been in existence from ancient times, while the new system development is recent (14 years);
- Topographical—the light soils of the undulating NIS command area are quickly drained once irrigation is cut off; and
- Managerial—so far the intensity of irrigation in NIS has been low, reaching only 103 percent per year, i.e, one crop per year, which does not allow enough water to sustain wet-zone type perennial crops throughout the year.

Aerial photographs confirm the importance of perennial vegetation in the area. Even in urban areas (called settlement areas or homestead gardens), the density of perennial vegetation is important. In homestead gardens, the vegetation is generally developed in three layers. The highest is composed of coconut trees, the medium, of fruit and medicinal trees

and the lowest, of vegetables and grass. It can be concluded that the whole area is an evaporative surface made of paddy fields, fallow lands, water bodies and perennial vegetation.

It must be pointed out that perennial vegetation is also found in nonirrigated areas of the dry zone. It is however mainly composed of shrubs and small drought-adapted trees, which evaporate much less than their well-fed counterparts in irrigated areas and in the Sri Lankan wet zone.

Schematic cross-section of the Kirindi Oya Project.



Causes of overestimation of water availability

Since its implementation, the Kirindi Oya project has supplied the whole area during the wet season, but it has not been able to provide enough water to sustain a second crop during the dry season for the entire project service area. An overestimation of water availability is often advanced as the reason for the gap between designed and actual irrigated areas. However, it is clear that water requirements have been based only on estimations of requirements for paddy (rice) without taking into account additional evapotranspiration from perennial vegetation. This is a major reason for the discrepancy between predicted and actual consumption.

Kirindi Oya is not an isolated example of this type of problem. All the major irrigation schemes in Sri Lanka (400,000 ha) in the dry part of the country are significantly covered with perennial vegetation. This situation is also very common in many areas of the humid tropics worldwide.

Perennial vegetation's impact on the water balance

Perennial vegetation has two major effects on the water balance:

- A reduction of the potential contribution of rainfall to crops; and
- An increase in evaporative depletion of water resources within the irrigated area.

It is well known that perennial vegetation reduces the rainfall contribution to runoff because of interception. Part of the rainfall is intercepted by the canopy, and evaporates directly without reaching the ground.

Tropical perennial vegetation transpires on a continuous basis throughout the year. Because roots can tap groundwater, transpiration rates are at full level during much of the year. Therefore, it was hypothesized that consumption of water from perennial vegetation in irrigated areas is high in terms of volume per unit area at Kirindi Oya.

The source of water for perennial vegetation is directly from rainwater and indirectly from irrigation supplies. Irrigation supplies and rainwater percolating past the root zone enters a shallow groundwater system where it can be tapped by tree roots. Without extensive vegetation, part of this water will reenter the drainage system, be available for crop evapotranspiration, or flow out to the Indian Ocean.

Benefits of perennial vegetation

The water consumption by perennial vegetation must be understood in terms of both the water balance and the non-intended but beneficial outputs. Perennial vegetation, whether planted on homesteads, or growing naturally in irrigated areas, has contributed substantially to the improvement of the

Beyond research: IWRM is a people-to-people challenge

If we leave aside the technical approaches and constraints surrounding water resources management we are left with people. People are both the beneficiary of water resources and the cause of its misuse. They are the key component in making Integrated Water Resources Management (IWRM) work. For those who think it naïve or simplistic to reduce the IWRM question to interactions between people, consider some real-life examples from Sri Lanka, taken from our research.

- The town of Kurunegala, population 50,000, lies between a rural farming area, which supports around 100,000 people, and the Maguru Oya River. Wastewater from the town has polluted the river to the point where it is unfit for domestic use – forcing local residents to travel several kilometers to get water for their homes and vegetable gardens. The population of Kurunegala is served by piped, treated water. The rural population depends on poor-quality river water and shallow wells fed by the river.
- In the Dedru Oya basin, five percent of the local population (total 870,000) is served by piped water. The remainder of farmers and domestic users in this area depend on water from shallow wells. The government's goal is to provide safe drinking water to the entire population by 2010. When the authorities explore the possibility of tapping the Mangala irrigation tank for domestic water supply, they come up against fierce resistance from the local farming community, who oppose any access to this water that is not for agriculture. Research shows that the tank can supply water for farming and domestic use if responsibly managed.
- Sand mining to supply the construction industry is a useful and profitable enterprise practiced in several river basins in Sri Lanka. If done in a non-planned way (as is often the case) mining deepens the river as it empties into the sea and deforms the river's banks. The result is a surge of salt water for several kilometers inland – killing crops and filling domestic wells with undrinkable water.

In each of these cases, the root of the problem is the same. There is no mechanism for any of these conflicting water users to meet and discuss solutions. This is a lack of Integrated Water Resources Management. IWRM brings accountability to all user sectors in a river basin, with the goal of achieving the harmonious development of the basin so that all users can coexist, causing the least degradation possible.

A concept which has often been distorted – to the detriment of the world's poor – is that water belongs to a country's national heritage, and its use should not be regulated. In large countries with small populations, this thinking might have been valid in centuries past. In today's world, the unaccountable use of water and the lack of coordination between water-user sectors serves only to allow the inefficient development of water, leaving less water and opportunity for the poor.

K. Jinapala is an IWMI research associate from Sri Lanka.

environment as a whole (Wickramasinghe 1992). There are many benefits to the presence of perennial vegetation:

- It provides shade and coolness, thus allows escape from the harsh tropical sun.
- It allows for increased biodiversity within the ecosystem.
- Homestead forestry is an important source of income for farmers.

As in other regions such Kerala in southern India (Salam and Sreekumar 1991), homestead gardens in Sri Lanka are of great importance to farmers. They provide them with food, medicinal plants, fuel, a pleasant environment, and raw materials for handcrafts. One of the favorite trees planted by farmers in their forestry gardens is the coconut palm tree which is called 'the tree of life' because every part of it is used (Persley 1992): the kernel, leaves, shell, husk, trunk, coconut water and roots. In addition to homestead gardens, natural vegetation along rivers, ditches and canals represents another source of water depletion, which has to be accounted for in water balances.

Rethinking irrigation 'efficiency'

The main finding of this study is that in the Kirindi Oya system, perennial vegetation is a significant factor in the use of water resources (43%), while only 22 percent of the available water is really consumed by crops. As perennial vegetation is a common feature of

Water balance for Kirindi Oya.

Inflow (Mm^3)					
Irrigation	Rain	Storage variation	NET INFLOW	Committed	Available
245[a]	230[a]	3[a]	478[a]	47[b]	431[c]

Outflow (Mm^3)				
Available water	Uncommitted	crop process depletion	Non-process depletion	
			ET from non-beneficial vegetation, evaporation from fallow	ET from beneficial non-crop vegetation
431 100%	96[a] 22%	95[c] 22%	56[c] 13%	184[d] 43%

[a] Measured [b] Estimated [c] Measured + Estimated [d] Closure of the balance

many irrigated areas in the humid tropics, planners should consider rethinking traditional criteria for design and performance assessment in these areas.

Improving water productivity is a priority for many decision makers and managers, and a reliable water balance is the ground on which strategies for improvements must be built. This water balance study demonstrated that evaluations based on classical notions of efficiency are inadequate. A better approach is to calculate the rate of beneficial utilization, which is the ratio of consumption by beneficial uses to the amount of water available for use in the irrigated area. Classical efficiency calculations yield 22 percent while the rate of beneficial utilization is 65 percent. Classical efficiency does not take into consideration the beneficial use by trees.

The significance of these findings is that common approaches to irrigation management and performance assessment are not adequate to deal with irrigation systems with a high degree of beneficial consumption of water by trees. There is a need for approaches in design, management and performance assessment that explicitly include other beneficial uses of water. This paper gave evidence from one location in Sri Lanka. We feel that there are many other locations worldwide where this is true.

REFERENCES

Bakker, M; R. Barker; R. Meinzen-Dick; and F. Konradsen, eds. 1999. Multiple uses of water in irrigated areas: A case study from Sri Lanka. SWIM paper no. 8, 1999. IWMI Colombo.

Persley, G. J. 1992. Replanting the tree of life: Towards an international agenda for coconut palm research. Wallingford, UK: CABI; ACIAR; Technical Advisory Committee of the CGIAR. xii, 156p.

Salam, A. and D. Sreekumar. 1991. Kerala homegardens: A traditional agroforestry system from India. In *Agroforestry Today* 3:2 (1991).

Wickramasinghe, A. 1992. Trees for sustainable survival. In Proceedings of the 3rd Regional Workshop on Multipurpose Tree Species. Bangkok May 1992. Ed. Prof. H.P.M. Gunasena, Faculty of Agriculture University of Peradenyia. Sri Lanka. p 144-170.

Daniel Renault is an Irrigation Specialist, seconded to IWMI from 1995 to 1999 by the Ministry of Agriculture, France. David Molden is leader of IWMI's Integrated Water Management for Agriculture theme. Manju Hemakumara is a research associate at IWMI.

The paper presented is based on a published article, reprinted from Agricultural Water Management, Vol 46, Renault et al, "Importance of water consumption by perennial vegetation in irrigated areas of the humid tropics: Evidence from Sri Lanka", pp. 215-230, Copyright 2001, with permission from Elsevier Science.

This research has been conducted with financial support from the Government of France (Ministere de l'Agriculture et dela Peche, Ministere des Affaires Etrangeres).

Sustainable Smallholder Land & Water Management Systems

Identifying promising smallholder water and land management systems, including solutions developed by poor communities.

Evaluating high potential systems; finding ways to transfer them to help other poor areas.

Promoting the uptake of these innovations through increased institutional capacity of national partners.

Research Themes:

Integrated Water Management for Agriculture • Sustainable Smallholder Land & Water Management Systems
Sustainable Groundwater Management • Water Resources Institutions & Policies • Water, Health & Environment

Low-cost irrigation for poverty reduction

An evaluation of low-head drip irrigation technologies in Kenya

S.N. Ngigi, J.N. Thome, D.W. Waweru, H.G. Blank

Summary

Unreliable rainfall causes periodic droughts in Kenya. This unpredictability, coupled with the lack of local capacity to deal with the situation, creates a persistent threat of household food insecurity in the region. Low-head drip irrigation technologies were introduced to combat this problem and alleviate food insecurity for thousands of people. First indications from a variety of research sources are that these technologies are a formidable poverty-fighting tool.

IWMI research evaluated the low-head drip systems most commonly available in Kenya. The purpose of this research was to identify and address the technical constraints of the systems and to develop practical recommendations for smallholder farmers, so that they can maximize the benefits of this technology.

Low-head irrigation technologies were introduced in Kenya in 1995 by Christian Mission Aid. The Kenyan Agricultural Research Institute (KARI) has been promoting the technology since 1996.

Until recently, Kenyan smallholders, mostly women, struggled to maintain kitchen gardens, using hand-watering to cultivate vegetables for their families. Hand-watering of vegetable gardens is tedious and inefficient especially where water is scarce. It requires many trips back and forth to the water source (which is often some distance away), and it does not deliver water down to the root zone (Reaves 1995). Rather than go through this tedious and time-consuming irrigation process, many people chose to go without vegetables in their diet during the dry season.

Today, they use low-head irrigation technologies in the form of bucket drip kits to deliver water to their crops effectively, with far less effort and for a minimum cost. Hundreds of poor families that use bucket kits during the dry season have shown that it is possible to produce enough vegetables for their domestic use and even for sale (Lusaka 1999).

Use of the drip kit is spreading rapidly in Kenya and the majority of drip users (some 70-80%) are women (Winrock 2000). Women do most of the gardening in Kenya, and would often carry water from distant water sources to hand-water their vegetables.

Low head drip irrigation technology: Advantages and disadvantages.

Advantages	Disadvantages
• Water saving—a large reduction in the amount of water needed for growing vegetables • Labor saving—plots can be irrigated quickly, simply by filling the bucket • Fewer disease problems, such a mold and powdery mildew (fungal), caused by soil splashing onto plant leaves (Baobab 1998) • Low-cost—the system is priced to fit poor farmers' budgets • Simple to install, operate and maintain • Easy to adapt to meet farmers' particular needs; for example, Ouko (1998) reported that some farmers in the Suba district along Lake Victoria, are fixing 30-m drip lines (rather than the usual 15 m) to larger 50-liter buckets to accommodate longer growing beds • Profitable for small-scale farmers—enabling them to produce enough vegetables for their families and for sale	• Breakage of the filter plug due to brittleness of the plastic used • Less flexibility in terms of emitter spacing and lateral lengths • Easily punctured by sharp objects if poorly handled • Clogging of some emitters • Nonuniformity of emitter discharge along the lateral, especially where land is not well leveled • Lack of spare parts and inadequate extension services • Leakage, especially at bucket connections, if fittings are not done properly, i.e., if the hole is bigger than the adapter; other causes of leakage are punctures, cracks. • Insecurity: fear of theft if the system is installed far from the house • Pest attraction—being the only green spot, especially during the prolonged dry spells, insects, rodents, aphids, etc., find refuge in the drip gardens; porcupines in search of water have even been reported to puncture drip lines in the Suba district (Ouko 1998) ***(Winrock 2000)***

Improved household nutrition and incomes

Drip kits do have disadvantages *(see box)* but the positive socioeconomic impacts seem to outweigh them. Farmers reported gross profit margins ranging between Ksh. 4,000-10,000 ($80-200) with a single bucket kit per season, depending on the type of vegetable (Winrock 2000), and between Ksh. 20,000-30,000 ($400-600) per season with the 1/8 acre kit (Nyakwara et al. 2000; Winrock 2000). These kits enable farmers to grow high-value crops, and they create employment opportunities in the rural areas. This adds up to a significant potential for poverty alleviation.

Take the case of Mrs. Mutai (KARI 1998). She is one of 150 women who were members of a group that started using drip irrigation in Eldoret. The system was installed in December 1996. Four months later, she had already sold enough vegetables to invest in more lines and make her garden bigger. Another member of the women's group, Anne Butia, has sold Ksh 10,000 ($200) worth of vegetables in three months from her tightly-fenced garden. Neighbors used to walk 10 kilometers to another district to buy vegetables but now they buy them from her. She has used the extra income to pay school fees and buy clothes for her family.

These and other cases show that low-head drip irrigation is proving to be a promising technology for responding to shortages of water and food in arid and semiarid areas. Low-head drip irrigation technologies promise improved food security and increased incomes at the household level, ultimately culminating in a healthy national economy (Winrock 2000). Ndiritu (1999) goes further, saying that "the bucket kit is the salvation of our country, as it allows the poorest of the poor to produce vegetables under conditions that previously would have only produced starvation and death."

Types of low-head drip systems

With low-head drip irrigation the oversophisticated and overengineered control elements used in the conventional drip systems are minimized and replaced by simple do-it-yourself equipment—low-head drip irrigation technologies.

Low-head drip systems operate under pressures of 0.5-2 m water head compared to the 10-15 m water head needed for standard drip irrigation (Gilead 1985). Small reservoirs such as oil drums can be used as header water tanks. These are supported on blocks so that the water pressure falls within the required range. Perforated flexible plastic piping conveys water to the plants. Low-head drip irrigation technologies includes gravity drip irrigation and bucket and drum kits.

Gravity drip irrigation

Gravity drip irrigation makes use of very low pressures. It fits into the infrastructure of existing channels, ditches and gravity-irrigated fields. Due to the low pressures, the system is very sensitive to ground elevation differences and special drip laterals operating under the above-mentioned condition are used (Gilead 1985).

The low operating pressure has many advantages for the design of gravity drip irrigation. These include:

- Enables substantial enlargement of the cross-section of the labyrinth flow passage of each emission unit, which simultaneously will minimize or even avoid clogging.

Translating research into practical tools for farmers

From science to smallholder

'Smallholders' are those women and men farmers who use rainwater and sometimes irrigation water to grow crops on their own land, rented land, or common ground. The majority of farmers in developing countries are smallholders. Many of them have little land and water and little or no money or credit to manage, and they are not empowered to participate in management at village or district level. Smallholders often have no choice but to exploit their land and water resources in ways that lead to widespread and serious environmental damage.

Hundreds of millions of smallholders hardly benefit from past research on land and water management because they do not know about it, and because recommendations are too vague, tools are too impractical or solutions too expensive. Yet much relevant knowledge and expertise does already exist. The challenge before us is to bring practical knowledge and useful tools from research to the minds and hands of small farmers. Through IWMI's research on smallholder land and water management, we work for rural smallholders that farm sloping lands, for those that have no choice but to farm old, infertile soils in the upland parts of river basins and for farmers who are trying to make ends meet in peri-urban areas.

Water and nutrients from the soil are essential to grow crops. Providing an adequate balance of these 'inputs' maximizes the efficiency of investments in both.

Our research goal is to produce more appropriate knowledge and better-adapted tools specifically for smallholders, to help them achieve the optimum water/nutrient balance–consistently and on a long-term basis. Armed with these improvements, farmers can use their water and land resources more effectively and get reasonable returns on their investments. This increases their income and encourages investments in natural resources–to make their use sustainable.

To achieve this goal of putting practical interpretations of our research into millions of smallholder farmers' hands requires considerable 'reach'. We are doing this by building partnerships with National Agricultural Research and Extension Services (NARES), whose task is to do exactly this. We are developing recommendations and tools with NARES, testing and improving them with the help of farmers, and supporting NARES in their efforts to disseminate the results to smallholders and this synergy will create the conditions that substantially improve the well-being of many smallholders, and make use of natural resources sustainable.

Dr. Frits Penning de Vries, is the leader of IWMI's theme on sustainable smallholder water and land management systems.

- The drip rate can be reduced down to 1.2l/h/m, despite the large flow passage.
- Lower drip rate means larger lateral lines and diameter reduction of the distribution and main lines and also of the other control elements.
- It enables use of a lateral produced from a very thin but still very strong plastic film made from a specially tailored polymer, which helps to reduce gravity drip irrigation lateral costs to a minimum.
- Optimal growing conditions can be achieved because the very low drip rate enables round-the-clock irrigation at peak season.

Advances in drip irrigation technology have made it possible to develop a simple bucket/drum kit system that low-income families can afford (produced by Chapin Watermatics). For several years, bucket kit drip irrigation has helped thousands of families provide fresh vegetables for their families. It has proved especially useful in water-scarce areas where water has to be carried for long distances—requiring that every drop is used in the most efficient way possible.

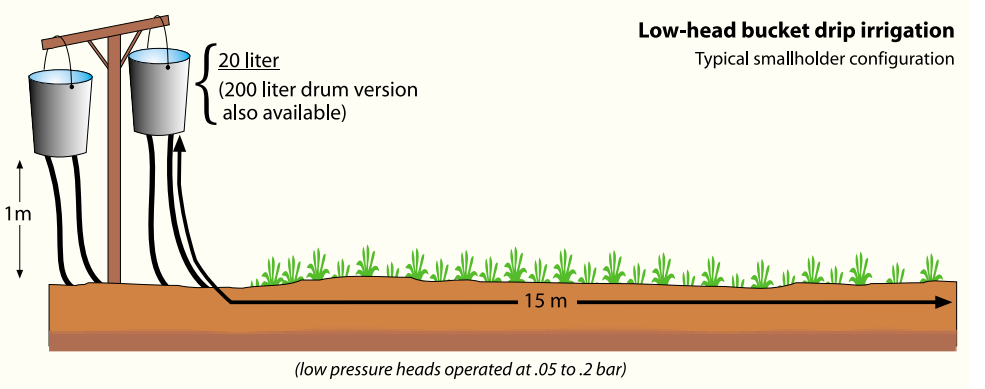
Overview of drip kits and lines available in Kenya.

Type of system/tape	Supplier(s)	Emitter spacing (cm)	Wall thickness (mm)	Tape diameter (mm)	Current cost (Ksh. and US$)
Chapin	KARI, FPEAK	30	0.25	16.0	950 per kit ($19)
T-Tape 520	Booth	20	0.50	16.0	12 per meter ($0.24)
Typhoon 25	Amiran	40	0.63	15.4	16 per meter ($0.32)
Victoria	ShadeNet Ltd.	30	0.50	16.0	9 per meter ($0.18)
Waterboys	KARI, for demonstration	30	0.15	16.0	2,800 per kit ($56)

In Kenya, this simple technology is being promoted by KARI and the Fresh Produce Exporters Association of Kenya (FPEAK) in cooperation with Chapin Third World Projects. The system is gaining popularity and is being used by many families in the Eldoret, Ngong, and Kajiado districts in the Rift Valley province; Gatundu and Ndeiya-Karai in the Central province; Tharaka, Machakos and Kitui in the Eastern province, and in many other drought- prone areas. In addition to Kenya, the bucket kit has also been implemented in Zambia, Mozambique, Malawi, Swaziland, South Africa, Namibia, Uganda and Nigeria (Chapin 1998).

Bucket and drum drip kits

The bucket kit is a small-scale drip irrigation system with high water use efficiency that operates at low pressure heads of 0.5 to 2.0 m (0.05-0.2 bar). It consists of a 20-liter



bucket or a 200-liter drum, drip tape, filters, rubber washers, male and female adapters, two supply tubes and barb fittings. A 0.75-inch screen filter with a flow ranging from 0.9 to 2.5 m^3/h is provided with the drip kit.

The bucket is mounted on a stand, which holds it one meter above the ground. The drip lines are supplied in lengths of 15 m, and, for best results, they are laid on level ground. If the drip lines go up a small slope, the bucket or drum should be placed on the highest side. The lines are laid with the emitters facing up to reduce the problem of sediment settling on the emitters. In the case of the drum system, the drum is connected to a manifold with five openings, each located to cover a bed. The manifold includes a PVC pipe, bends, gate valve, tees, and glue for fitting.

Comparison of the available drip lines in Kenya

There are many suppliers of different commercial drip systems in Kenya. The majority of existing drip lines are designed for high-pressure systems. There are few specifically designed low-head drip lines. These include Chapin, T-Tape and Waterboys. IWMI research evaluated these, and the most commonly available high-head drip lines for use with low-head systems.

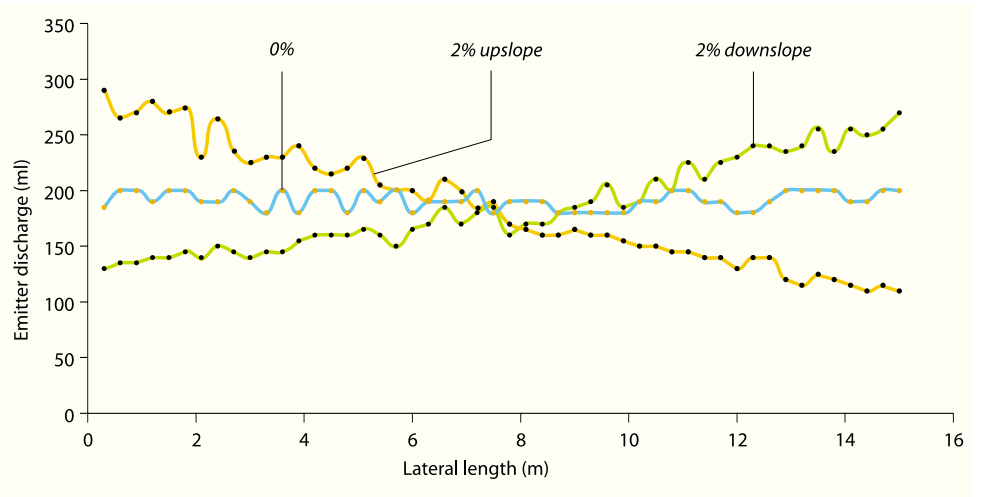
Two common problems experienced by farmers using low-head drip systems are uneven water distribution, especially on sloping land, which can drastically affect yields due to under-irrigation of some plants and over-irrigation of others; and the tendency of emitters to clog. IWMI research tested existing low-head drip irrigation systems in an effort to overcome or at least minimize some of these constraints.

Recommendations for farmers using low-head drip systems

Readily available high-head drip lines can be adapted for use with low-head systems. In addition to Chapin system drip lines, the existing high-head drip tapes, e.g., Typhoon, T-Tape and Victoria, can be used for low-head (as low as 0.5m) bucket kit systems without substantially affecting performance (water distribution uniformity along the drip tape for various supply head, lateral length and land slope). This means low-head drip kits can be assembled locally with readily available high-head drip tapes and fittings.

Land slope has more effect on water distribution uniformity than either head or lateral length. Different drip tapes perform differently with respect to the three parameters evaluated—land slope, lateral length, and water supply head. Thus discharge rates vary with head, slope, lateral length and type of drip tape. Water distribution uniformity decreases with the lateral length, though different tapes perform differently, e.g., for T-Tape, length increases beyond 20 m have no significant effect on water distribution uniformity. Although water supply head seems to have no significant effect on water distribution uniformity, there is a slight improvement with increase in head, especially for high-head-designed tapes. The effect of head is significant for sloping land. However, land slope has more effect on water distribution uniformity than either head or lateral length.

The effect of land slope on water distribution for Victoria driptape.



To adapt to the performance variation between the two drip lines of a kit, farmers should grow crops with higher water demand on the side of the higher performing line. Water distribution varies between the two drip lines of the bucket kit. The difference in performance could be attributed to either one line being a bit lower than the other, more leakage on one line or more clogging on one line. These factors could lead to pressure differences and hence the variations in water distribution. Farmers can adapt to this difference by growing the crops with higher water demands on one side.

For sloping land, the bucket should be placed up-slope; the crops with the highest water demand should be planted down-slope. Water distribution uniformity decreases with an increase in land slopes, whether up-slope or down-slope, but down-slope drip kit layout gives a better water distribution uniformity than up-slope layouts. If land is sloping, as is normally the case, it is advisable to place the bucket on the higher side, i.e., down-slope. For sloping land, high water-consumption crops should be planted on the downstream side while less water-consuming crops should be planted upstream.

Implications of combining any two parameters. The combined effect of any two parameters: water-supply head and land slope, water supply-head and lateral length, and land slope and lateral length revealed that:

- It is not advisable to use longer lengths (beyond 7.5 m) for sloping land.
- It is advisable to use higher head (1.50 m) for longer lateral lengths.
- Water uniformity distribution improves significantly with increase in supply head for sloping land, especially for up-slope layout. Up-slope layout is recommended with high water supply head.

Filters can be improv ised out of common household materials to prevent emitter clogging. To improve water distribution uniformity, a filter which is an important component of the drip kit, is used to prevent emitter clogging. Waterboys, which have no filter, seem to be prone to clogging. Locally available "filter" material, e.g., used lady's stockings, mosquito nets, etc., can be improvised as a form of *'jua kali'* filter.

REFERENCES

Chapin, R. D. 1998. Bucket kit news.

Gilead, G. G. 1985. Gravity Drip Irrigation (GDI) System. Proceedings of the Third International Drip/Trickle Irrigation Congress. California, U.S.A. ASAE Vol. II.

KARI. 1998. Simple drip irrigation makes a big difference on small farms. *Harambee*-pulling together for Kenya. A report of the Kenya National Research Project. KARI, Nairobi.

Lusaka, N. 1999. Bucket kits in Kenya. Bucket Kit News, Chapin Living Waters Foundation. Unpublished report.

Ndiritu, C. 1997. Quoted from Chapin Living Waters Foundation Brochure.

Ouko, B. 1998. Kenya Islands Mission Drip Irrigation Programme. Proceedings of Workshop on Small-Scale Drip Irrigation Experience Sharing Workshop. 28-30 September, 1998, Kitui Kenya.

Reaves, R.E. 1995. Third world faith in action. *Irrigation Journal* 45(6). Adams Trade Press.

Winrock. 2000. Proceedings of Low-Head Drip Irrigation Review Workshop. 17-18 February, 2000, Nairobi, Kenya.

S.N Ngigi, J.N. Thome, and D.W. Waweru are from the University of Nairobi's Department of Agricultural Engineering; H.G. Blank was IWMI's regional representative in Eastern Africa up until August 2000.

This research is part of a series of projects and investigations by IWMI and its partners, examining various aspects of small-scale and informal irrigation in southern and eastern Africa.

The research was carried out with support from the African Development Bank.

Sustainable Groundwater Management

Developing and promoting a more accurate understanding of the socio-ecological value of groundwater, and the nature and scale of the consequences of its unsustainable use.

Developing and disseminating research knowledge on promising technologies and management approaches that can help achieve sustainable groundwater use.

Exploring sustainable solutions and sharing with strategic players in national and regional groundwater systems.

Research Themes:

Integrated Water Management for Agriculture • Sustainable Smallholder Land & Water Management Systems
Sustainable Groundwater Management • Water Resources Institutions & Policies • Water, Health & Environment

Using monsoonal river flows to recharge groundwater: An experiment in India

R. Sakthivadivel, A.S. Chawla

Summary

In 1987, the government of Uttar Pradesh constructed the Madhya Ganga Canal to divert surplus monsoonal river flows for development of kharif (wet season) irrigation in dry pockets of the Ghaziabad, Bulandshahr and Aligarh districts, and to intensify paddy cultivation in the existing command of the Upper Ganga Canal.

Seepage losses from the 115-kilometer unlined canal, the newly developed system it supplies (the Lakhaoti Branch system), and from paddy fields were expected to recharge the rapidly declining aquifers in the area. This stored water could then be used to irrigate a second crop during the dry season (rabi).

An IWMI study evaluated the success of the project in 2000. The main conclusion of this research is that for the climatic and hydrogeologic conditions of the Indo-Gangetic Plain, an unlined kharif irrigation system such as the Lakhaoti Branch appears to be an effective way to recharge groundwater over a large area.

In 1989, IWMI undertook a two-year study in collaboration with Roorkee University, the Water and Land Management Institute of Uttar Pradesh and the State's Irrigation Department to model groundwater system behavior in the areas affected by the new canal. The purpose was to develop a sustainable management regime for conjunctive use of groundwater and surface water.

In 2000, an IWMI research team returned to the Madhya Ganga Canal Project (MGCP) to document how diversion of surplus Ganga water during kharif season has affected the groundwater level, land use, cropping pattern, and the costs and benefits of agricultural operations. The larger objective of this study was to determine if diverting monsoonal flows for paddy cultivation is a viable option for artificially recharging groundwater in similar geohydrologic settings. For the present analysis, only the newly developed area, the Lakhaoti Branch system, is considered.

Background

The western part of the Indo-Gangetic Plain (IGP) receives rainfall ranging between 650 and 1,000 mm, most of which is received in the three months of the monsoon period. Out of this amount, only around 200 mm percolate through the soil layer to recharge groundwater aquifers.

Before the construction of the Madhya Ganga Canal and the Lakhaoti Branch System, the source of irrigation in the study area was primarily groundwater. Groundwater was pumped through State tube wells, private tube wells, Persian wheels and dug wells. Total withdrawal of groundwater in the area was exceeding recharge and, therefore, the water table was progressively declining. There was only enough water for one cropping season, during kharif; during the rabi season there was not always sufficient water.

A surface storage dam was not a good solution in view of the high cost of construction, the nonavailability of suitable places for constructing such a dam in this flat alluvial terrain and stringent environmental requirements. Instead, the Government of Uttar Pradesh chose to utilize existing subsurface storage (aquifers) to capture monsoonal flows. Monsoonal flood water is diverted to grow paddy and other crops during the kharif season. Seepage from unlined channels and irrigated fields increase recharge to the groundwater reservoir, making additional groundwater available for irrigating crops during the rabi season.

Overview of the Project

The Madhya Ganga Canal Project (MGCP) involved the construction of a barrage across river Ganga at Raolighat, which diverts 234 m^3/sec of water into the Madhya Ganga Canal. This canal feeds the existing Upper Ganga Canal system and the newly constructed Lakhaoti Branch Canal.

The Lakhaoti Branch Canal commands an area of 193,000 ha; the proposed area under paddy cultivation is 49,500 ha. Head discharge of the branch canal is 64 m^3/sec. The

length of the branch canal taking off from the MGC is 72 km. The length of the distribution channels of various capacities is 1,030 km. In the head reach, the Lakhaoti Branch has a bed width of 35 m, water depth of 2.25 m, and a bed slope of 15 cm/km. At the tail reach, discharge is 20 m^3/sec, bed width reduces to 14 m and water depth to 1.56 m. Canal water input into the area has varied between 27,202 m in 1988 and 64,301 m in 1996. All main canals and distribution systems are unlined earthen canals.

The canal water use balance indicates that in the initial years, canal water was not used very efficiently, but did serve to recharge the groundwater. Conveyance losses were estimated to be about 98 percent of canal water input in 1988; these had dropped to 48 percent by 1998. There is scope for further reducing the conveyance losses, while still recharging groundwater. Field water application losses have ranged between 1 and 19 percent of canal water input.

Impact of the project on groundwater levels

Groundwater data collected from 102 observation wells for the years 1984 to 1988 (84 maintained by the State Groundwater Department and 18 by the Central Groundwater Board) were used for this study. In order to study the behavior of the water table in space and time, water table depth below ground level, water table elevations, and the rise of the water table during the monsoon and fall of the water table during the

Figure 1. Water table elevation contours (meters above sea level) Post Monsoon 1984.

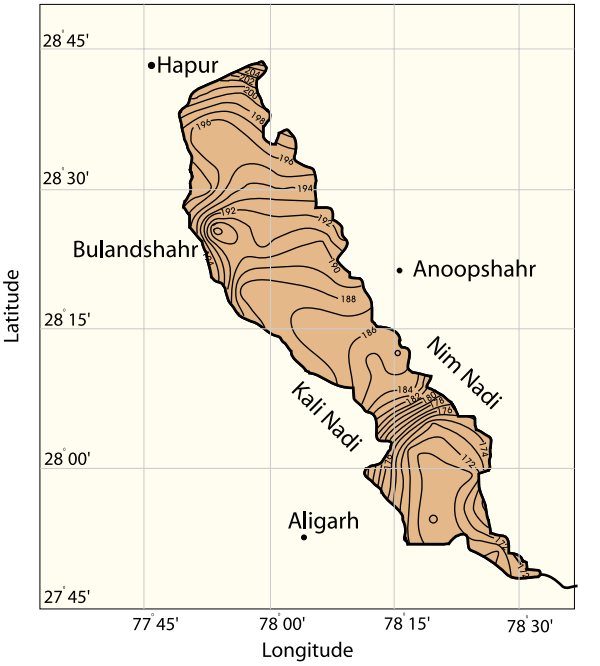
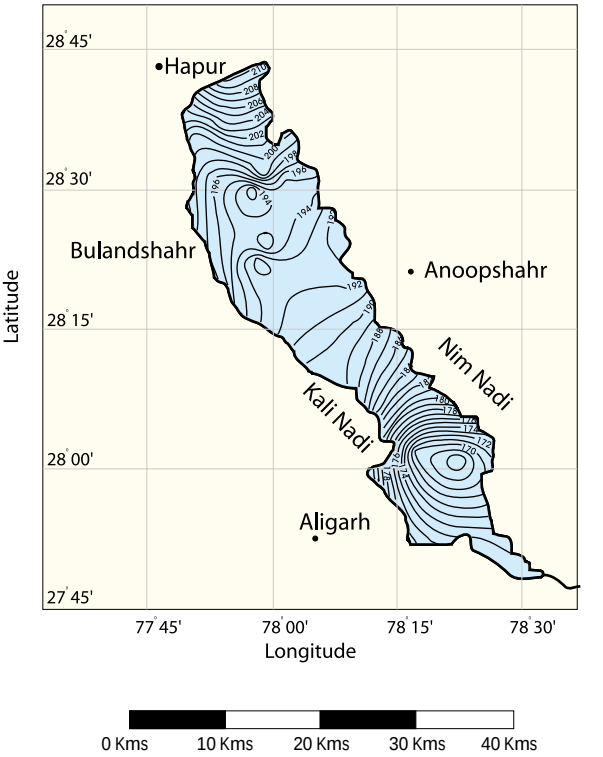


Figure 2. Water table elevation contours (meters above sea level) Post Monsoon 1998.



non-monsoon season were computed. Using the Krizig method of interpolation, water table elevation contours have been prepared for the pre- and post- monsoon seasons for all years of study. Typical post-monsoon contour plots for 1984 (pre-project) and 1998 (post-project) are shown in Figures 1 and 2.

In general, the water table shows a downward trend up until 1988 after which it starts rising due to canal water input. The water table in general had been going down progressively up to 1987-88, falling from 10 m below groundwater in 1984 to 12 m by 1988. After the commissioning of the Lakhaoti Branch in 1987-88, the water table started rising and in general continued rising steadily up until 1994. Between 1995 and 1996 the water table fell in some locations. This may be due to less rainfall in 1994 and 1995. The water table has again shown an upward trend during 1997, 1998 and 1999 due to better rainfall during 1996 and 1997 and larger canal water input.

On average, the water table rose to about 11 m below ground level in 1989 and continued to rise to 9.5 m in 1997. From 1997, it began rising rapidly and reached 6.5 m below ground level in 1999. Due to canal water input the downward trend was checked, and the water table has actually risen from 12 m to 6.5 m below ground level.

Benefits of the project on farm budgets

Before the construction of the Lakhaoti Branch Canal, the farmers in the Lakhaoti Command were dependent entirely on groundwater. The Lakhaoti Branch, supplies irrigation water in the monsoon season to irrigate the proposed area of 49,500 ha under rice cultivation. Seepage from the Lakhaoti Branch unlined system also refills the aquifers, enabling farmers to use recharged groundwater to irrigate a second crop during rabi.

Farm budget, with and without canal

			Without canal				With canal			
Crops	Yield Quintal/ ha 10 Quintals=1 Ton	Gross receipts	Cost of cultivation	Net benefits	Weightage	Weighted average	Cost of cultivation	Net benefits	Weightage	Weighted average
		18000								
Rice	22/35	21,000*	15,400	2,600	0.02	50	13,200	7,800	0.15	1,170
Maize	20	9,000	7,100	1,900	0.35	660	6,600	2,400	0.20	480
Bajra	20	8,000	7,050	950	0.10	100	6,150	1,850	0.10	185
Sugarcane	600	43,000	23,400	9,600	0.13	2,550	21,100	21,900	0.15	3,285
Fodder (K)				1,500	0.20	300		1,500	0.20	300
Total kharif					0.80	3,660			0.80	5,420
Wheat	35	17,000	11,000	6,000	0.60	3,600	10,200	6,800	0.60	4,080
Barley	35	17,000	10,700	6,300	0.10	630	9,800	7,200	0.10	720
Potato	200	50,000	18,000	32,000	0.03	960	17,300	32,700	0.03	980
Peas/Chana	20	15,500	10,000	5,500	0.07	390	9,250	6,250	0.07	440
Total rabi					0.80	5,580			0.80	6,220
Total annual					1.60	9,240			1.60	11,640

* Gross receipts for rice without canal = Rs. 18,000/hectare.
Gross receipts for rice with canal = Rs. 21,000/hectare.

Before the project, the cost of pumped groundwater had been increasing steadily due to the progressive lowering of the water table. After the introduction of the Lakhaoti Branch Canal, the cost of pumping has gone down as the water table has risen. Farmers have been able to raise the position of their pumps due to the rise in the water table.

According to simulation modeling, without canal water input the water table would have dropped to an average depth of about 18.4 m by 1999. This would have not only increased the cost of pumping, but also made it necessary for farmers to deepen their wells and lower their pump sets.

From resource 'development' to 'management': the paradigm shift we need to save groundwater

Groundwater offers us precious opportunities for alleviating the misery of the poor. But tapping this resource in a responsible way poses many complex and daunting challenges.

Around the world, the number of locations that have a sustainable groundwater balance is shrinking by the day. The many consequences of groundwater overdevelopment are becoming increasingly evident.

The problems and opportunities surrounding groundwater in Pakistan are a good illustration of the work to be done. Along with India, this country is one of the world's biggest users of groundwater, mostly for irrigation and also for domestic and industrial requirements. The massive development of groundwater from the Indus Basin aquifer started about 30 years ago. Today, groundwater provides the country with some 60 billion m^3–some 40% of the total irrigation water available. This source is tapped by 20,000 public and about 550,000 private tube wells. Some 70% of the tube wells are located in canal command areas, while the rest provides irrigation based on groundwater alone.

The tapping of useable groundwater gives farmers the supplemental irrigation they need to cope with the vagaries of the surface water supplies. But the uncontrolled and unregulated use of groundwater in this way has serious consequences. The lowering of groundwater tables, due to unsustainable use, increases the pumping cost–which often places the resource out of reach for the poorest members of society. Saline intrusion into fresh groundwater aquifers kills farming areas. Many planners and policy makers speak of *developing* water resources to serve the needs of more people. But what is needed is management– *sustainable management*.

If a business-as-usual approach is taken to groundwater use, these problems will only become more acute, widespread and visible. The frontline challenge is to put into operation a range of corrective mechanisms *before* the problem becomes insolvable. The foundation to these measures must be an attitudinal change, where people's thinking is changed from 'developing' the resource to 'managing' it.

But this paradigm shift cannot take place without a foundation of credible and accessible information that conclusively proves the need for management. Today, resource planning is severely hampered by limited and incomplete information on groundwater availability, quality, withdrawal and other variables. This is how research can help.

Asad Qureshi is a research associate at IWMI's regional office in Pakistan-his home country.

The cost of pumping at a water table depth of 18.4 m would have been approximately Rs. 4,650/ha.m. The cost of pumping groundwater at the actual 1999 water table depth, 6.5m, is Rs. 2,650 per ha.m—a savings of Rs. 2,000/ha.m for farmers. Considering that close to 90,000 ha.m are pumped annually, the amount saved in pumping costs comes to Rs. 180 million per year.

Weighted average net income per hectare for kharif and rabi seasons without the canal works out to about Rs. 3,600 and Rs. 5,580, respectively, for an annual income per hectare of Rs. 9,240. With the introduction of canal water, average net income has gone up to 11,640 per hectare—an increase of 26 percent.

The benefits of the project to individual farmers, in addition to a reduction in the cost of pumping include increased production, a better cropping pattern and better operational conditions. Paddy area has increased from 2 to 15 percent in the area and sugarcane from 13 to 15 percent.

Conjunctive use of groundwater and surface water

The kharif channel enables conjunctive use of surface water and groundwater. The farmers can pump groundwater for irrigation during the rabi crop season and also to supplement canal water, if necessary, during the kharif season.

Because the canal operates in the kharif season only, the farmers are forced to use groundwater for their second crop in the rabi season. This regime of sustainable conjunctive use of groundwater and surface water ensures that the water table is maintained at a reasonable depth and waterlogging conditions do not develop.

Water demand for domestic use (2,397 ha.m in 1997-98) and industrial uses (1,797 ha.m in 1997-98) are also met from recharged groundwater.

Project recommendations

There is considerable scope for improving management of the system to achieve the planned irrigated area under paddy and to ensure that water is distributed to the entire command. Construction of minors and provision of outlets has to be completed.

An aerial view of water distribution indicates that more water is being supplied to the head reaches. Here the water table has risen steadily due to seepage losses. In the lower reaches, the water table continued to go down after the project was implemented; it only began to rise after 1994. The water table has still fallen below its 1984 level in some areas in the lower reaches.

Concluding Remarks

Several methods of artificial recharge of groundwater are being tested and implemented in India. But, for the climatic and hydrogeologic conditions of Indo-Gangetic Plain, an unlined kharif irrigation system such as the Lakhaoti Branch appears to be the best arrangement for recharging the subsurface reservoir. The Lakhaoti Branch system demonstrates how monsoonal flows can be captured for use during the dry season, using subsurface reservoirs for storage, without the construction of a dam.

R. Sakthivadivel is a principal researcher at IWMI. A.S.Chawla is a retired professor from the Water Resorces Development and Training Centre (WRDTC), University of Roorke, India.

The work presented here is based on a forthcoming paper.

Water Resources Institutions & Policies

Identifying policy tools, organizational designs, and institutional frameworks to achieve high productivity of water in irrigated agriculture and improve people's lives.

Developing and evaluating research-based **guidelines for water policy reform and support systems** for more effective management of water in river basins.

Validating internationally established best practices and evaluating them for specific regional or subregional contexts.

Research Themes:

Integrated Water Management for Agriculture • Sustainable Smallholder Land & Water Management Systems
Sustainable Groundwater Management • Water Resources Institutions & Policies • Water, Health & Environment

Farmer management of government irrigation systems: A viable option for Africa's smallholders?

Tushaar Shah, B. van Koppen, D. Merrey, M. de Lange, M. Samad

Summary

This research assesses the widespread transfer of government-run smallholder irrigation schemes in Africa to the management of organized groups of farmers in the light of decades of experience by various countries. The comparative study of the Irrigation Management Transfer (IMT) suggests that it can work if certain preconditions are met. These include a supportive legal-policy framework, secure water rights, local management capacity building and the presence of an enabling process to facilitate management transfer.

Even with all these conditions fulfilled, this research finds that IMT is unlikely to work for African smallholders. Here, the institutional alternatives most likely to succeed are those that address the whole complex set of constraints that African smallholders face. The first step for African governments must be to enhance the income-creation potential of smallholder irrigated farming by strengthening market access, promoting high-value crops and improving systems for providing extension and technical support to smallholder irrigators. This approach, rather than focusing exclusively on the direct transfer of irrigation management, will help create the right climate for IMT in these regions.

In general, IMT or farmer-managed cooperative irrigation has worked in situations where individual stakes are high and the irrigation community has been able to take the additional burden of self-management—financial and managerial—in its stride. This ability is strongly linked with the microeconomics of irrigated production, which propels the typical farm household economy upward by generating powerful incentives for self-management.

In many respects, the situation of the sub-Saharan African smallholder differs from the situations found in areas where IMT has proven successful. *The path to sustainable institutional evolution for farmer-managed irrigation in the African smallholder context needs to take full cognizance of the differences and devise strategies that are appropriate to the special challenges faced by these schemes.*

Challenge 1: A history of dependency

The discussion of IMT in the African context in recent years began with management reforms that entailed the drastic curtailment of the functions of the parastatal agencies. These agencies were responsible for the provision of support services and management of irrigation schemes. Smallholder schemes were managed in an 'estate mode'; farmers, under parastatal management, did not make any entrepreneurial or managerial decisions.

In South Africa, for example, for over three decades, the Agriculture and Rural Development Corporation (ARDC) has managed smallholder irrigation schemes through an elaborate top-down command and support system, which has eventually proven unsustainable. Under a version of contract farming, irrigation to smallholders was fully subsidized, and the ARDC organized mechanized cultivation, planting and fertilizer application in the schemes.

All that the plot holders did was weed, harvest and move the irrigation pipes around. They did not deploy much working capital; nor did they need to make any decisions about farm management, which was pretty much centralized. The parastatal also organized the marketing of pooled produce; it deducted all its expenses before turning the residual sum, such as it was, over to farmers.

The support systems operated by parastatals for smallholder irrigation schemes in many African countries have left behind a strange legacy of impoverishment and dependency. In some cases, these had degenerated into oppressive 'spoils systems' that destroyed all preexisting informal institutions, thereby compelling farmers' dependency—and robbing them of their enterprising and elementary skills to manage input and output markets.

The parastatals' abrupt withdrawal has had a telling effect on smallholders. Cropped areas in many South African smallholder schemes dropped sharply in less than a year after government withdrawal simply because plot holders were unable to organize by themselves the working capital needed to hire tractors, buy seeds and fertilizers, and obtain services.

Challenge 2: High cash costs due to mechanization

Partly as an outcome of the 'estate-type' farming mode the parastatals adopted, African smallholder irrigated farming has turned into an unviable, high cash-cost enterprise. A major contributor to the high cash cost is the high level of mechanization of farm operations. Parastatals like the ARDC in South Africa used heavy equipment for ploughing and land preparation, spraying and harvesting. As a result, the tradition of using animal power has disappeared in many smallholder schemes.

With the withdrawal of parastatals, accessing equipment at affordable rates has emerged as a major problem. The development of local equipment rental markets has been slow and variable, and rental rates are high. This has squeezed the smallholder farm economy from two sides: the margins from irrigated farming have been hit and working capital requirements have increased.

Challenge 3: Absence of credit, input and output markets

Matters are complicated further for African smallholders by the missing or highly imperfect input and credit markets facing them. Most smallholder schemes in South Africa, for instance, are located in former homelands in remote areas away from towns and cities with which they often have poor linkages. With the rise of the 'estate mode of farming' under parastatals, such markets as existed previously gradually disappeared; and now that the parastatals have withdrawn, there is a huge institutional vacuum.

Challenge 4: Insecure land tenure

The African smallholder also suffers the disadvantages of communal landownership with insecure tenure. The present tenurial arrangement does not provide much room and incentive for uninterested farmers to sell out and for interested and capable ones to expand their holdings. Nor does it lead to the emergence of flexible rental markets in irrigated land, thus keeping it from achieving its full productive potential. As already mentioned, inability to offer land as collateral for obtaining credit works as another disadvantage. Often, the lack of clarity amongst the plot holders about what their rights precisely are with respect to their plots seems more problematic than the absence of ownership.

Challenge 5: Smallholder hedgehog behavior

The reading of international IMT experience suggests that all or a majority of farmers in successful IMT cases are full-time farmers deriving a substantial proportion of their livelihoods from irrigated farming. This builds their stake in self-management of their irrigation system and their willingness to commit time and resources to it.

In the African smallholder context, farmers who work tiny plots smaller than one hectare are forced to pursue what Robert Chambers calls the 'hedgehog strategy' of depending on a variety of sources of earning a livelihood. The inability to depend upon irrigated farming for all or a substantial proportion of their livelihoods forces menfolk to seek urban jobs while women stay behind to cultivate the plots.

The smaller the plot, the stronger this tendency. For instance, in a smallholder community in the Northern Province of South Africa studied by Johann Kirsten of the University of Pretoria, 75% of the households earned income from cropping but this amounted to just 5.8% of their total income. But 66% got remittances, which constituted 33% of the total income.

This has many implications. First, plot holders are often more interested in keeping their plots—as some form of a security or insurance—rather than working them to their full productivity potential. Second, there are stringent limits on the time, effort and resources a typical smallholder irrigator is willing and able to make on the irrigated plot if it involves sacrificing other livelihood options.

Third, the large number of members even on a small scheme greatly increases the invisible 'transaction costs' of collective self-management—such as costs of fee collection, responding to complaints, delivering water to each user, extracting consensus on key decisions, of checking 'wanton irrigator misbehavior of blocking canals, cutting off embankments, illegal lifting of water by pumps or siphons and breakage of control structures'—all invisible costs that vary directly with the number of irrigators.

IMT success factors

For students of institutions, South Africa's irrigation situation offers uncommon insight into what will work and what will not. Here, on the one hand, the government and NGOs are trying to coax smallholders, who are running away from farming, to accept IMT. And in this very same locale, we find some very successful water user organizations, composed of large-scale commercial farmers. These organizations, known as Irrigation Boards, have always turned government irrigation systems into their instruments for wealth creation.

When IMT was tried on government-managed irrigation systems in these 'white' areas, it clicked effortlessly. It did so because, first, IMT merely formalized and legitimized the high *de facto* farmer participation in irrigation management that existed from the start. With reasonably large farms (25-1,000 ha), access to capital to invest in commercial crops, and average household net farm incomes of up to US$150-250 thousand (see, e.g., Tren and Schurr 2000), South Africa's commercial farming community is ideal for IMT. Farming is their only (or the primary) source of livelihood and income; and in their case, the double-coincidence of *need* and *capacity* for IMT is well established. Smallholder groups have neither: their present tiny farms give them little net income (some suggest it is negative if full value of family labor is costed), and they do not have the resources and management capacity to operate their schemes viably.

The 'pattern of failure'

Crosby (2000), a leading South African observer writes: 'It is unbelievable that with the exception of sugar projects there are virtually no (smallholder irrigation) schemes that have been successful.. [and] the pattern of failure is so similar that it is not really necessary to undertake a needs analysis for individual projects'. This similar pattern of failure is what we refer to as 'downward ratchets'.

In Crosby's analysis, the downward ratchets are evident in the 'common aspects [which] are: total dependence→water-supply infrastructure dilapidated→ineffective water management→low production levels→little knowledge of crop production or irrigation→ineffective extension→lack of markets and credit→difficulty in sourcing inputs→expensive and ineffective mechanization services →unrepaired fencing →damaged soils.'

A policy proposal prepared by a group of South Africa's most experienced scholars, led by Professor Backeberg, appropriately asserts that: 'Irrigation farming can be very remunerative provided the following are present: high quality management, markets and infrastructure, and sufficient equity capital' (Backeberg et al. 1996). Africa's smallholder irrigation farmers have none of these; and without these, IMT can easily become a millstone around their neck.

Lessons for development professionals

In conclusion, our review of global and African experience suggests that nowhere in Africa is there a significant body of positive experience to suggest that straightforward Irrigation Management Transfer (IMT) will work in smallholder irrigation as it has in the US, Mexico, Turkey, New Zealand and Columbia.

Indeed, it would be surprising if, even with all necessary stress on 'process' and capacity building, IMT programs will meet even the moderate expectation of success, that it 'saves the government money, improves cost effectiveness of operation and maintenance while improving, or at least not weakening, the

Policy research must touch small farmers and the poor

Examples from South Africa

South Africa faces the considerable challenge of implementing its progressive National Water Act (Act 36 of 1998) to achieve the key objective of 'beneficial use in the public interest', which encompasses poverty eradication, economic growth and integrity of the resource base. Supporting this process is one of the priority tasks of IWMI's research theme on Water Resources Institutions and Policies in South Africa. We are working to help find answers to the water reform question in a context where *it is no longer sufficient to consider only the financial returns of allocations to the different water use sectors within river basins.*

IWMI is making contributions to this new knowledge base in several ways.

For the Department of Water Affairs and Forestry (DWAF), we are reviewing the process of establishing a Catchment Management Agency in the Olifants River Basin. An important aspect of this work is advising how poor communities can participate meaningfully in the consultation processes on the establishment of the Agency and in the formulation of a future catchment management strategy.

We are well placed to play a central role in policy development, implementation and testing of Water User Associations, which have been newly introduced into South African water legislation. Here, our focus is helping small-scale irrigators to benefit from lessons learned – locally and in other countries where IWMI works – in the realm of sustainable institution-building.

The topic of gender and poverty is of particular relevance in the South African context, where the majority of small-scale farmers are women and rural poverty is rife. IWMI has completed several studies with local partners to profile the plight of these women and assist in policy formulation to improve their livelihood opportunities. This work includes research on small, robust and affordable technologies like treadle pumps, which are well-known and widely used in South Asia currently but not available in South Africa. This is a good example of how our researchers' detailed knowledge of situations and practices in many regions (in this case research in East Africa and South Asia) can be of direct benefit to smallholder farmers in another area (southern Africa).

Dr. Marna de Lange is an IWMI researcher and South African stationed at the Institute's new regional office in Pretoria.

productivity of irrigated agriculture.' There are important questions about the viability of most smallholder farming itself, leave alone irrigation systems. IMT may well be the last straw in the collapse of a smallholder agriculture run for decades in an 'estate mode', and barely surviving on the oxygen of government subsidies and supports.

This is not to say that African smallholders do not or cannot manage irrigation; or that they cannot engage in sustainable cooperation. Indeed, some of the most efficient, livelihood-creating irrigation types in Africa is private smallholder irrigation. Similarly, there are many outstanding examples of large-scale cooperation amongst small-scale dryland farmers of Africa. But transferring the management of government irrigation schemes involves a different ball game all together.

For example, most of South Africa's 180 smallholder schemes would not have been built if they were to be turned over to farmers because their financial viability was always doubtful unless water users generated fairly high levels of income/ha. And no reasonable planner would have ever assumed that smallholders would attain value-productivity levels comparable to commercial farmers unless they had access to truly high-quality support institutions.

Lesson 1: IMT has to make good economic sense to farmers

We often think that building people's economic institutions is essentially a matter of 'getting the process' right. This is one of the many situations that shows that nothing could be further from truth, especially in catalyzing economic institutions. No amount of 'process and organizational savvy' or collective vision-building will get a group of rural poor—in Africa or in Asia—to accept a deal that does not make good 'here-and-now' sense to them. And where the deal does make sense—as IMT did for Irrigation Boards—virtually no investment was required in instituting an 'organizing process'.

South Africa's Irrigation Boards are as outstanding examples of self-organizing irrigation institutions as are North Gujarat's tube well companies; both show that people organize swiftly—and without the benefit of catalysts or facilitators—when organizing makes good economic sense. If development professionals have problems organizing poor people around an idea, they must take a hard look at what they're offering; most often, it would be a rotten deal.

Lesson 2: The larger the number of farmers involved, the higher the management costs

IMT faces problems in smallholder communities not because smallholders are less able or less cooperative but partly because most of them are half-hearted farmers and more importantly, because the management cost of an irrigation system—like most service institutions—increases faster with the number of customers than with the volume of business. A 1,500 hectare system that serves 1,500 irrigators costs much more to manage—in terms of the logistics of service delivery, fee collection, maintenance, and so on—than a similar system that serves 5 large farmers. Moreover, it is a lot easier for 5 large customers to come together and agree to the rules of self-management than for 1,500 smallholders to do.

Lesson 3: IMT must offer improved livelihoods at an acceptable cost

Where irrigated farming is a viable enterprise, IMT will work if the cost of sustainable self-management is a small proportion of farming incomes. Where this is not the case, IMT will eventually fail. Indeed, four conditions must be met before a farming community makes a success of an IMT intervention:

- IMT must hold out the promise of a significant improvement in the life situations of a significant proportion of members involved.
- The irrigation system must be central to creating such improvement.
- The cost of sustainable self-management must be an acceptably small proportion of improved income.
- The proposed organizational design must have—and be seen to have—low transaction costs.

Lesson 4: To work, institutional reforms need to go beyond irrigation management

While sectoral thinking makes good analytical sense for organizers and analysts, for the poor people, only livelihood thinking makes sense. In the African smallholder situation, for instance, irrigation departments' concern is institutional reform only in the irrigation sector; but what smallholders need is broad-based multi-sectoral institutional reform, sweeping credit, input and output markets, land tenure and extension services. For, only such broad, multi-sectoral institutional reforms will make their unviable farming viable.

The institutional alternatives that have the best chance for success in the smallholder situation are those that help smallholders move to a substantially higher trajectory of productivity and income from where they can take, in their stride, the additional cost and responsibility of managing their irrigation system. The best place to start seems to be markets. Bring smallholder communities in contact with stable, reliable markets for value-added products. Once their irrigated holdings provide them with decent livelihoods, African smallholders will be ready and eager for IMT.

REFERENCES

Backeberg, G. R; T. J. Bembridge; A. T. P. Bennie; J. A. Groenewald; P. S. Hammes; R. A. Pullen; and H. Thompson. 1996. Policy proposal for irrigated agriculture in South Africa. Discussion Paper. Pretoria: Water Research Commission.

Crosby, Charles. 2000. A review of planning and design priorities applicable to small-scale farmer irrigation plots. Draft for NPDALE, Govt. of Northern Province, RSA.

Tren, Richard; and Michael Schur. 2000. Olifants river irrigation schemes: Crop data and irrigation management structures for four separate irrigation schemes. Draft paper for the International Water Management Institute.

Tushaar Shah is a principal IWMI researcher and leader of the Sustainable Groundwater Management Theme; Barbara van Koppen is an IWMI researcher and gender expert working in Africa; Douglas Merrey is director of the Institute's Africa Regional Office; Marna de Lange and Madar Samad are IWMI researchers based in South Africa and Asia, respectively.

The paper presented here is based on the research article, "Institutional Alternatives in African Smallholder Irrigation: Lessons from International Experience in Irrigation Management Transfer" (forthcoming).

This work was carried our under a research grant provided by the British Department for International Development (DFID) for research on support systems for sustainable smallholder irrigation management in the Olifants basin of South Africa.

Water, Health & Environment

Raising awareness and encouraging the incorporation of health safeguards in water management planning in rural and urban areas.

Documenting the relationships between water, health and environment and develop tools for planning and management.

Developing practical tools to quantify and manage irrigation water and drainage flows to sustain ecosystems while obtaining optimal irrigated agriculture production.

Research Themes:

Integrated Water Management for Agriculture • Sustainable Smallholder Land & Water Management Systems
Sustainable Groundwater Management • Water Resources Institutions & Policies • Water, Health & Environment

Risks and Benefits of Wastewater Irrigation

Finding a balance between small farmers' needs, and impacts on health and environment

Christopher A. Scott, J. Antonio Zarazúa, Gilbert Levine

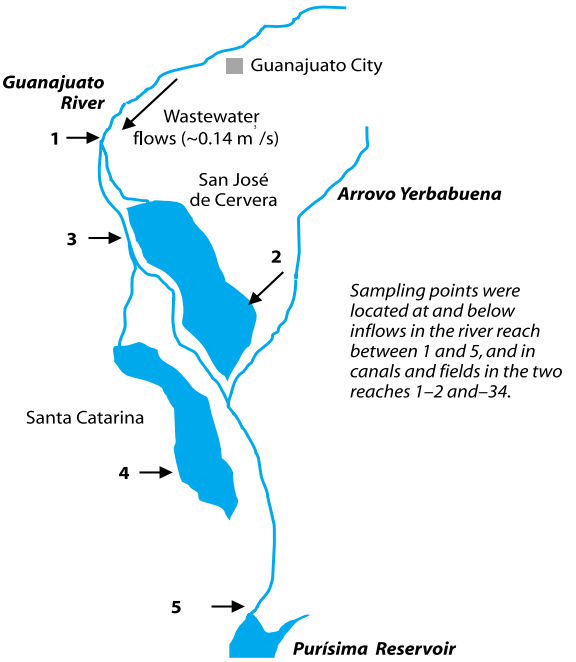
Summary

There are significant trade-offs associated with irrigation using untreated urban wastewater. From a river-basin perspective, wastewater irrigation is an important form of water and nutrient reuse; however, there are important water quality, environmental, and public-health considerations. The risks associated with this practice are increasingly recognized, both in terms of implications for public health, and impacts on the environment. Less well-recognized are the potential benefits from this discharge.

In the water-short Guanajuato river basin in west-central Mexico, urban wastewater is a primary source of irrigation water and nutrients for small farmers. The 140 hectares of land irrigated with raw wastewater downstream of the city of Guanajuato serve as a *de facto* water treatment facility. The City is currently considering construction of a wastewater treatment plant. IWMI research assessed the benefits of the wastewater to farmers and the health and environmental risks associated with the practice. This initial study suggests that continued application of the wastewater to the land would be a much more economical form of wastewater treatment. This conclusion is drawn with the caveat that the potential for serious negative impacts for health and the environment should be evaluated in an ongoing monitoring program.

The City of Guanajuato's basic water supply includes both surface water, impounded in two principal reservoirs located in the upper part of the watershed, and groundwater pumped from one main aquifer in the central part of the watershed. It releases wastewater to the downstream part of the watershed, ultimately reaching the Purísima reservoir, which serves as the water source for part of Irrigation District 011 (where IWMI has been working since 1994). Given the water-short conditions in the basin (annual precipitation of 500 mm, potential evapotranspiration exceeding 1,500 mm,

Schematic map of the study site.



and significant urban and agricultural demand for water), storage levels in the reservoir are chronically low.

Benefits of wastewater irrigation

Since the groundwater costs approximately six times as much as the gravity surface water, the City has a strong interest in maintaining the water-producing characteristics of the watershed as well as in the potential for use of the wastewater to reduce demands on the city water supply.

Similarly, the current users of the wastewater have interests in the future availability of wastewater. These users are small-scale irrigators, organized in *unidades,*[1] whose water sources include the wastewater, flows from natural rainfall, and groundwater. The wastewater represents a significant part of their water supply, especially during the dry season. The typical crops grown are forage (alfalfa) and grains (sorghum and wheat).

The City is currently planning to construct a wastewater treatment plant and to sell the water to a proposed golf course. The IWMI study assessed the monetary impact on the small farmers, based on the estimated levels of water and nutrients derived from the untreated wastewater.

[1]*Unidades* are organizations of irrigators that are user-managed, often with some governmental oversight.

Nutrient value to farmers

The research evaluated the Interactive River Aquifer Simulation (IRAS) model, developed by Cornell University, as a tool for modeling the flow of water and nutrients to farmers' fields. Two sets of waste-load inputs corresponding to untreated and treated wastewater discharged by the City were simulated using the IRAS model. This reflects the City's plan to treat and sell its wastewater to commercial interests. Under the assumption that treated wastewater will be released down the natural river channel to be used by irrigators of the customary San José de Cervera Canal (SJC) and Santa Catarina Canal (SC) until such time that the commercial buyer actually acquires the water, we have simulated the difference in nutrient delivery to crops between the untreated and treated wastewater.

Total N and P deliveries to irrigated fields using untreated and treated wastewater.

	Untreated		Treated		% Change	
Canal	N (kg)	P (kg)	N (kg)	P (kg)		
San José de Cervera (SJC)	45,483	7,553	3,556	711		
Santa Catarina (SC)	63,865	10,308	11,397	1,698		
	N (kg/ha)	P (kg/ha)	N (kg/ha)	P (kg/ha)	N (%)	P (%)
San José de Cervera	455	76	36	7	-92.2	-90.6
Santa Catarina	1,597	258	285	42	-82.2	-83.5
Alfalfa requirements	88	115	88	115		

The proposed treatment plant is designed to remove approximately 90 percent of both the Nitrogen (N) and Phosphorus (P) in the waste stream. Based on the modeling results, this represents a nutrient value of US$95,900. Using the recommended level of N and P for the crops planted, the foregone nutrient benefit has a value of US$18,900 per year. While the value of these nutrients to society is included in the gross value cited above, the loss of these inputs to the farmers is such that their net incomes would be reduced by the cost to replace the nutrients lost.

Unit costs of Nitrogen and Phosphorus fertilizers.

Source of N	% N	Cost (N$/50 kg)	Cost (US$/kg N)
Urea	46.0	87.50	0.40
Ammonium Nitrate	33.5	82.50	0.52
Ammonium Sulfate	20.5	36.50	0.37
Average			0.43

Source of P	% P	Cost (N$/50 kg)	Cost (US$/kg P)
Super Triple	46.0	112.50	0.51
Simple Sulfate	18.0	47.50	0.56
DAP	46.0	137.50	0.63
MAP	52.0	140.00	0.57
Average			0.57

Application cost (combined N+P) (US$/ha)			31.58

Note: *N$=Mexican pesos.*

Water value to farmers

The water used for irrigation represents a recycling of urban wastewater in a basin context. Data from IWMI studies indicate that irrigation water has a gross value of output per hectare of irrigated land[2] of approximately US$1,800, and of a cubic meter of water of US$0.16. For the 140 hectares of land irrigated by the wastewater of the City of Guanajuato, this implies a water value of US$252,000 per year. The water value of wastewater used for irrigation represents a significant monetary benefit to both the society and the water users.

Reduced cost of wastewater treatment

The estimated investment cost for the wastewater treatment plant is US$2.6 million with an annual operating cost of US$200,000. While the field study and analyses were limited, they strongly suggest that continued application of the wastewater to the land

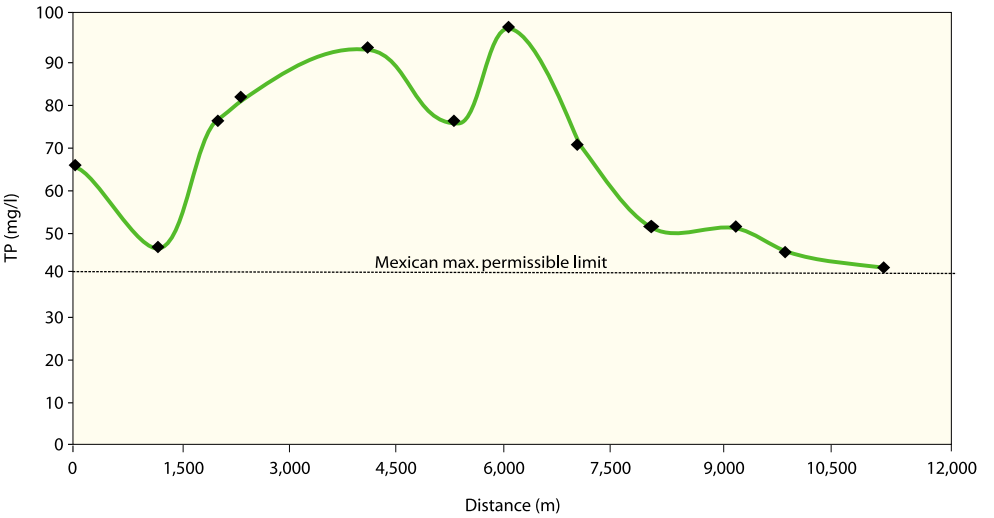
[2]This was based upon a crop mix of wheat and maize, with a relatively small percentage of vegetables. The cropping pattern in the wastewater-irrigated area includes wheat, barley and alfalfa, the last being a relatively high-value crop.

would be a much more economical form of wastewater treatment. This conclusion is drawn with the caveat that the potential for serious negative impacts for health and the environment should be evaluated in an ongoing monitoring program.

Risks associated with wastewater irrigation

In spite of the short-term benefits received from wastewater irrigation, there are considerable medium- and long-term costs associated with this practice. In the study area, N was found in excess of the 40 mg/l Mexican norm for receiving waters. There is also an indication that elevated N levels in irrigation water may contaminate wells with nitrate. However, the limited well-water-quality sampling performed as part of this study did not find levels above the 10 mg/l (as N) US drinking water standard.

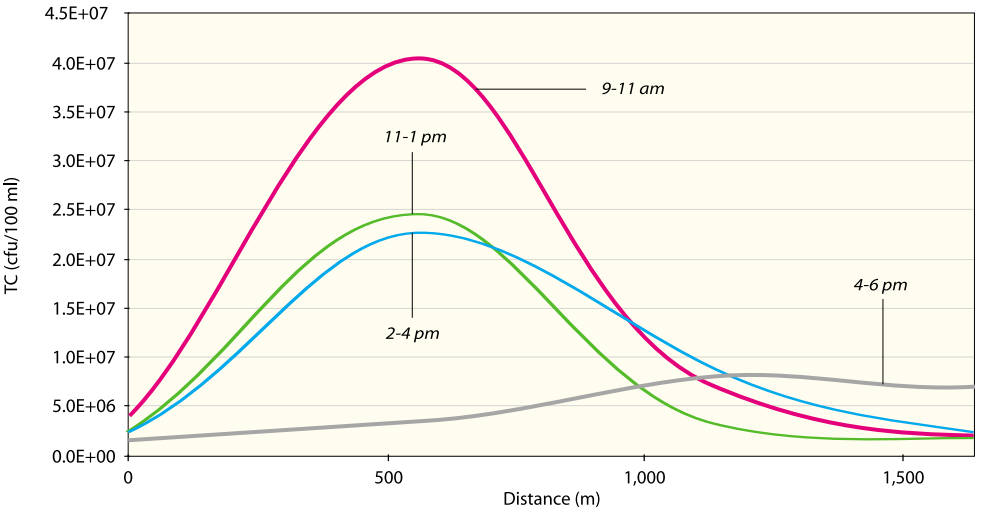
Total Nitrogen with distance down the main river channel.



Adverse health impacts

The potential for adverse health impacts of irrigation with wastewater has been reported in a number of articles, but there was no obvious indication of adverse health impacts in the area of study. The successive reuse of the wastewater in this particular basin suggests that these adverse effects may be smaller than in situations without reuse.

Total coliforms with distance down the main river channel.

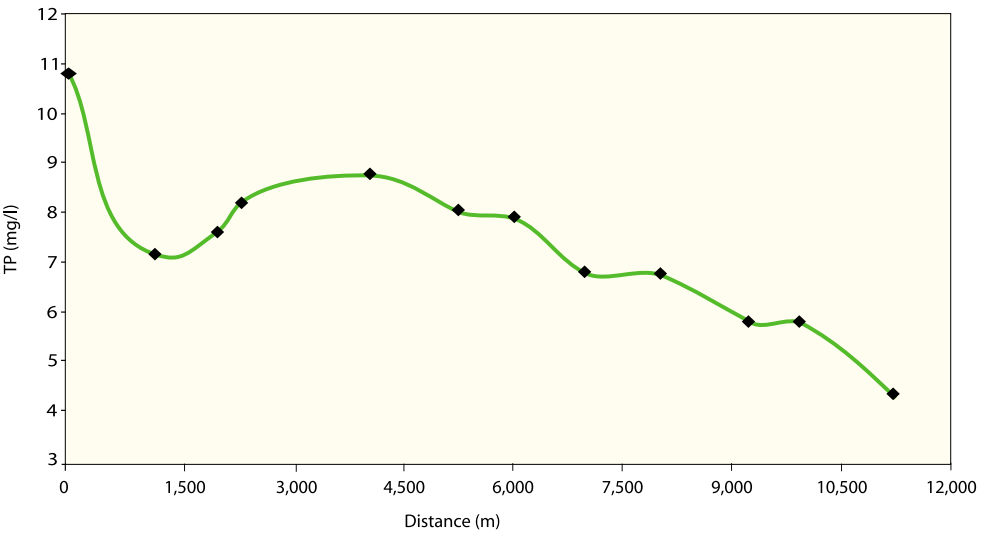


The passage through field vegetation and/or the filtration that accompanies irrigation and subsequent runoff and drainage would be expected to reduce the level of parasites and other microorganisms, in addition to the observed changes in chemical concentrations.

Adverse environmental impacts

The major environmental impact that could be anticipated is increased eutrophication in the Purísima reservoir, due to the P inputs from the wastewater. While the

Total Phosphorous with distance down the main river channel.



concentration of P in the water is relatively high, the flow from the wastewater path represents a small percentage of the total annual flow into the reservoir. Despite the dilution of TP, the reservoir's trophic status has produced some algae problems. Similarly, the salinity contribution from the wastewater source, while at a higher level due to the reuse upstream, is not likely to represent a significant problem.

The extended use of wastewater for irrigation also carries with it the potential for accumulation of heavy metals. The available information did not permit the determination of rates of accumulation because of potentially large changes in wastewater composition resulting from historic changes in mining in the region, as well as changes in the urban population.

Notwithstanding this, the levels found in our limited field study suggest that heavy metals do not represent a significant problem. The composition of the waste stream is likely to vary tremendously from city to city depending on the type and number of industries. We have noted that the City of Guanajuato may not be representative with respect to heavy metals.

Finally, although we have identified and described a number of short-term benefits associated with wastewater irrigation, the longer-term trade-offs associated with the practice must be considered carefully, chiefly for reasons of irreversibility. Nevertheless, the difficulty of financing adequate wastewater treatment in developing countries makes land application an attractive alternative.

Christopher A. Scott is a Senior Researcher at IWMI; J. Antonio Zarazúa is a Research Assistant; Gilbert Levine is an IWMI Fellow.

The paper presented here is based on IWMI Research Report 41: "Urban-Wastewater Reuse for Crop Production in the Water-Short Guanajuato River Basin, Mexico".

This research was conducted with financial support from the Taiwan Council of Agriculture, the Tao Yuan Foundation for Irrigation Research (Taiwan) and the T. Sao-Jin Memorial Foundation for R&D for Agriculture and Irrigation (Taiwan).

People cannot live by food alone

They need to be healthy in body and mind and live in harmony with their surroundings.

More than two million children die each year of diseases arising from biologically contaminated water, and countless more millions have their physical and mental development retarded as their energy is sapped by repeated battles with these diseases. Thousands more suffer illness and a slow death by drinking water contaminated by chemicals like arsenic and fluoride bubbling up from deep groundwater, or by cadmium and mercury seeping out with the waste from nearby industries. Why do they drink this contaminated water? Because they have no alternative.

Water also gives life to deadly mosquitoes that transmit malaria–the disease that afflicts 300-500 million people and kills more than a million each year. And to the snail hosts that harbor the parasite that causes schistosomiasis, a disease afflicting 200 million people each year. Most of this suffering and death occurs in developing countries, which can least afford such burdens.

We at IWMI proudly proclaim that our mission is to help eliminate poverty in the developing world by managing water used in agriculture more effectively. We do this by looking at ways to produce 'more crop per drop'. But predictable crop yields and sustainable agricultural practices are only part of the picture. People cannot live by food alone. They need to be healthy in body and mind and live in harmony with their surroundings. Focusing on crops alone, and ignoring the health and well-being of these farmers will bring no joy and not alleviate poverty.

Starving nature of its water needs in order to produce food, too, will fail because a degraded environment is bound to strike back eventually. We have recognized this reality and so IWMI's mission, too, has evolved, to become: *'Improving water and land resources management for food, livelihoods and nature'.*

A nice motto.....but also a daunting challenge. How can these often conflicting needs be balanced? How to safeguard peoples' health, protect the environment and still produce enough food with our limited freshwater resources? This is the purpose of our research, to look for these answers.

Dr. Felix P. Amerasinghe, is a Principal Researcher (entomologist) in Water, Health and Environment.

Donors & Board of Governors – 2000

During 2000, IWMI's funding support was provided by the following governments, development banks, agencies and foundations:

- **African Development Bank**
- **Asian Development Bank**
- **Australia**
- **Belgium**
- **Canada**
- **Care/Nepal**
- **China**
- **Denmark**
- **Ford Foundation**
- **France**
- **Germany**
- **India**
- **Iran**
- **Japan**
- **Netherlands**
- **Norway**
- **Peru**
- **South Africa**
- **Sweden**
- **Switzerland**
- **Taiwan**
- **Turkey**
- **United Kingdom**
- **USA**
- **World Bank**

The Governments of India, Iran, Mexico, Nepal, Pakistan, South Africa and Sri Lanka provided program support for IWMI-related activities in those countries.

BOARD CHAIR

Prof. K.J. Beek (The Netherlands)
Professor in Land Evaluation, International Institute for Aerospace Survey and Earth Sciences (ITC),
The Netherlands

VICE CHAIR

Mr. Remo Gautschi (Switzerland)
Assistant Director General, Swiss Agency for Development Cooperation, Switzerland

Dato Ir. Shahrizaila bin Abdullah (Malaysia)
Chairman, Bangunan KTA Tenaga, Malaysia

Dr. Zafar Altaf (Pakistan)
Secretary, Ministry of Food, Agriculture and Livestock, Pakistan

Mr. S.B. Bandusena (Sri Lanka)
Secretary, Ministry of Irrigation and Water Resources Management, Sri Lanka
(w.e.f. 20 November 2000)

Dr. Mayra Buvinic (Chile)
Chief, WID Program Unit and Inter-American Development Bank, Chile

Dr. Mona M. El-Kady (Egypt)
Chairperson, National Water Research Center, Egypt

Dr. W. David Hopper (Canada)
Partner, D&R Associates International, U.S.A.

Dr. Walter Huppert (Germany)
Senior Advisor, GTZ, Germany

Ms. Joan Joshi (U.S.A.)
Management Consultant, U.S.A.

Mr. Asger Kej (Denmark)
Managing Director, Danish Hydraulic Institute, Denmark

Dr. Benoit Lesaffre (France)
Head, Research and Forward Studies Service, Department of Regional Planning & Environment
Directorate of Economics Affairs and Environmental Evaluation, France

Mr. Jaliya Medagama (Sri Lanka)
Secretary, Ministry of Irrigation and Power, Sri Lanka (up to 19 November 2000)

Dr. Toru Mase (Japan)
College of Agriculture, Akita Prefectural University

Prof. Frank Rijsberman (The Netherlands)
Director General, International Water Management Institute, Sri Lanka
(w.e.f. August 2000)

Dr. David Seckler (U.S.A.)
Director General, International Water Management Institute, Sri Lanka (up to July 2000)

Dr. Eugene Terry (Sierra Leone)
Advisor, Agricultural Research, Rural Development Department, The World Bank, U.S.A.

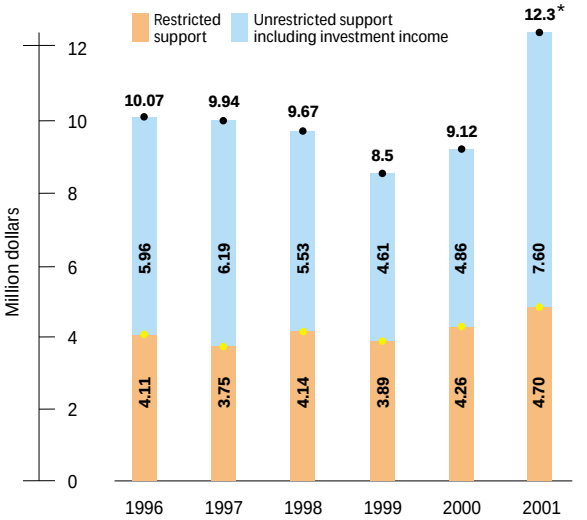
Financial Overview – 2000

In 2000, the net assets of the Institute recorded an increase of $320,000 compared to the decrease of net assets of $50,000 in 1999.

In 2000, the Agreed Agenda revenue amounted to $9.1 million. Unrestricted income amounted to $4.3 million.

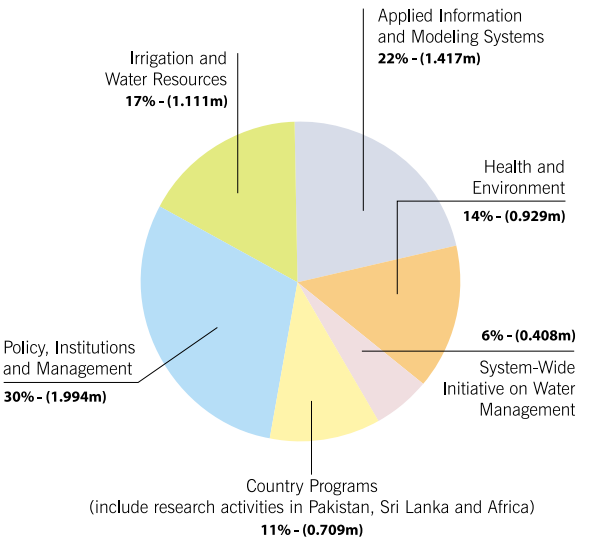
In 2000, the Institute had 110 research staff, of whom 28 were internationally recruited. The Institute also had 6 associate staff (seconded by donor organizations) and postdoctoral fellows. IWMI's total staff numbered 258.

Income 1996 - 2001.



*of which 1.565 is former IBSRAM.

Research Expenditure by Program - 2000.



Restricted Research Contracts over $50,000 Awarded in 2000

Smallholder water management systems—Promoting innovative water harvesting and Irrigation systems to support sustainable livelihoods in South Asia (DFID, UK)—$433,000 over 3 years

This research is identifying a pool of promising technologies and practices, suitable for small farmers in South Asia, and short-listing 10-12 innovations for detailed scrutiny. This includes assessing the impact of adopting the innovations on poor households and communities, and identifying the institutional and hydrogeological environment within which each innovation can succeed. The final outcome will be an 'innovation analysis', including guidelines and recommendations for governments and rural communities.

Agro-ecosystem management for human health in the Uda Walawe irrigation scheme, Sri Lanka (IDRC, CANADA)—$99,300 over 3 years

The goal of this research is to increase the productivity of water in the Uda Walawe basin while reducing human health risks and protecting the environment. Specific objectives are to:

- develop a methodology for an integrated approach to agricultural water management in river basins, taking into account human health and environmental considerations;
- evaluate the impact of different water management regimes on: (i) vector breeding, (ii) availability of water for domestic purposes; and
- estimate the requirements for agrochemical inputs under different water management regimes and cropping patterns.

Global dialogue on water for food and environmental security (World Bank)—$400,000 over 2 years

The objective of this work is to bring actors together in a decentralized program of activities under the auspices of consortia of key actors, not to develop an "IWMI program". The key activities during the proposed preparatory phase are to:

- initiate development of a broad coalition of interests related to water for food and environmental security for a dialogue on strategic directions;
- bring together the research institutes that can jointly provide a comprehensive assessment of costs, benefits and future directions in irrigated agriculture; and
- facilitate identification and formulation of a comprehensive set of innovative approaches to water management for sustainable food production and rural development at the local and regional level—carried out by a range of actors.

Institutional Development and Policy Reforms for Improving Water Management, Kazakhstan (ADB)— $56,120 over 1 year

The activities under this grant include:

- reviewing the Government of Kazakhstan's plans, policies, and institutional arrangements for the irrigation subsector
- formulating specific recommendations relating to: amendments to key policies, regulations, plans for the irrigation subsector; division of responsibilities within the irrigation subsector at different levels; institutional mechanism for irrigation management transfer; proposed (or existing) internal structures of water user associations; measures to enhance the role of women; capacity-building initiatives and human resources development
- developing a phased implementation plan incorporating the above.

Systemwide Initiative on Water Management (SDC, Switzerland)—$90,651 over 1 year

SWIM covers research on a range of policy, institutional, and technical issues. Research involves the combined efforts of IWMI and other CGIAR centers. The most recent SWIM project is "The Changing Face of Irrigation in Kenya", an in-depth study covering the different dimensions of irrigation in the country, the challenges faced by small farmers and the ways in which they are meeting those challenges. The result of this work will be key lessons and research areas for consideration in the ongoing restructuring of the irrigation sector in the eastern and southern Africa region.

Unrestricted, Agreed agenda—2000

	Donor	Grants 2000 US$'000	Grants 1999 US$'000
Unrestricted	Australia	190	128
	Belgium	61	118
	Canada	203	204
	China	10	10
	Denmark	362	309
	Germany	196	219
	India	38	38
	Japan	215	315
	Mexico		(10)
	Netherlands	480	198
	Norway	116	127
	Sweden	279	359
	Switzerland	243	249
	United States of America	690	552
	World Bank	825	830
	Subtotal (Unrestricted)	**3,908**	**3,646**
Other Revenue	Investment income	287	211
	Sundry income	65	58
	Subtotal (Other Revenue)	**352**	**269**
	Total (Unrestricted Resources)	**4,260**	**3,915**
Agreed Agenda – Restricted			
	Asian Development Bank	508	265
	African Development Bank	120	211
	Australia	135	105
	CARE/Nepal	1	
	Canada	59	8
	Denmark	18	57
	Ford Foundation	179	408
	France	156	239
	Germany	420	341
	International Food Policy Research Institute (IFPRI)		3
	International Development Research Centre (IDRC)		34
	Iran	112	107
	Japan	755	750
	Netherlands	68	119
	Norway		73
	Pakistan	25	
	Peru	30	
	South Africa	137	6
	Sri Lanka	14	
	Sweden	134	272
	Switzerland	91	
	UNESCO	6	
	Taiwan	34	80
	Turkey	267	
	United Kingdom	239	159
	United States of America	97	62
	Water and Power Development Authority (WAPDA)–Pakistan	112	
	World Bank – Pakistan	269	517
	World Bank	1,103	566
	Subtotal - Agreed Agenda	**4,856**	**4,615**
	Total Income	**9,116**	**8,530**

Statement of Financial Position December 31, 2000 and 1999

	2000 US$'000	1999 US$'000
Assets		
Current Assets		
Cash and cash equivalents	4,980	5,288
Accounts receivable:		
Donors	1,188	1,157
Employees	120	91
Others	113	117
Inventories	30	40
Prepaid expenses	155	152
Total Current Assets	**6,586**	**6,845**
Property and equipment, net	1,207	1,619
Other Assets	1,338	2,188
Total Assets	**9,131**	**10,652**
Liabilities and Net Assets		
Current Liabilities		
Accounts payable		
Donors	1,598	3,384
Employees	208	184
Others	347	478
Accruals	114	47
Total Current Liabilities	**2,267**	**4,093**
Long-Term Liabilities		
Accounts payable		
Employees	826	840
Total Long-Term Liabilities	**826**	**840**
Total Liabilities	**3,093**	**4,933**
Net Assets		
Unrestricted		
Appropriated	3,300	3,295
Unappropriated	2,738	2,424
	6,038	**5,719**
Restricted	–	–
Total Net Assets	**6,038**	**5,719**
Total Liabilities and Net Assets	**9,131**	**10,652**

The following list is limited to projects with an annual budget over US$50,000. All budget totals are shown in US dollars.

Theme 1: Integrated Water Management for Agriculture

Comprehensive Assessment of Water Management in Agriculture

Assessing the past societal and environmental benefits and costs of water-management activities for food production, and evaluating possible future directions (contribution to Global Dialogue on Water, Food and Environment).

Budget 2001: $1,055,720 (restricted and unrestricted)

Iran-IWMI Program of Joint Research Activities

Working with the Iranian Agricultural Engineering Research Institute and Esfahan Research Station to understand interaction of water management practices at different levels in the Zayandeh Rud basin, Esfahan Province.

Budget 2001: $259,230 (restricted)

Global Dialogue on Water, Food and Environment

Strengthening a viable dialogue at national and local levels; creating a platform for local or basin-scale activities that enhance food and environmental security; encouraging the exchange of experience and the development and identification of best practices.

Budget 2001: $242,000 (restricted)

Water Productivity in India and Pakistan

Exploring water management and other factors that lead to high water productivity through comparative analyses of irrigation systems in northwest India and Pakistan's Punjab.

Budget 2001: $200,410 (restricted)

Conjunctive Water Management in South Asia

Developing and testing methods of controlling waterlogging and salinity through effective conjunctive management of surface water and groundwater supplies in Pakistan.

Budget 2001:$153,580 (restricted)

IPTRID-IWMI Research and Knowledge-Networking Project

Developing strategies and options for smallholder water management systems in Asia and sub-Saharan Africa; benchmarking irrigation performance; promoting the use of water management/food security tools, such as the IWMI Policy Dialogue Model, PODIUM, in Asia and sub-Saharan Africa.

Budget 2001: $150,000 (restricted)

More Rice with Less Water, China

Documenting and evaluating water-saving practices in China at Zhang He Irrigation System in Wuhan, China.

Budget 2001: $93,880 (unrestricted)

African Development Bank (AFDB) Program Support

Improving equity and productivity in water-scarce basins in South Africa; evaluating low-cost precision irrigation techniques suitable for small farmers in East and Southern Africa; enhancing the productivity and sustainability of rice-based systems in West Africa; evaluating the impact of alternative irrigation regimes on water productivity and malaria in a rice irrigation scheme in Kenya.

Budget 2001: $82,990 (restricted)

Hydrology for Environment, Life and Policy (HELP) in the Olifants Benchmark Basin, South Africa

Improving the links between hydrology and the needs of the society through the creation of a decision-support tool, which gives the user access to data collected in the basin, and through capacity building with Catchment Management Agency (contribution to the UNESCO initiative).

Budget 2001: $76,950 (unrestricted)

Eco-Water Savings, Sri Lanka

Water accounting, testing of water-saving practices, modeling and monitoring activities to understand the impact of various irrigation activities on ecological reserves in the Uda Walawe benchmark basin.

Budget 2001: $72,030 (restricted and unrestricted)

Monitoring of Water Savings and Competition, Aral Sea Basin

Evaluating the effectiveness of various incentives to conserve water for farmers, cooperatives (water user associations) and water supply organizations.

Budget 2001: $86,380 (restricted and unrestricted)

Theme 2: Sustainable Smallholder Land and Water Management

Management of Soil Erosion Consortium

Combining biophysical research with socioeconomic research on catchment management by different stakeholders (Indonesia, Laos, Malaysia, Nepal, Philippines, Thailand, Vietnam).

Budget 2001: $814,280 (restricted and unrestricted)

Management of Sloping Lands for Sustainable Agriculture in Asia

Developing methods of soil conservation on sloping lands through a network of seven countries (China, Indonesia, Laos, Malaysia, Philippines, Thailand, Vietnam).

Budget 2001: $243,910 (restricted and unrestricted)

Integrated Nutrient Management

Investigating recycling of nutrients from organic waste in cities in the form of compost and wastewater to crops in urban and peri-urban areas.

Budget 2001: $204,855 (restricted and unrestricted)

Poverty-Focused Smallholder Water Management

Identifying and testing promising smallholder water-management innovations for transfer to other poor areas.

Budget 2001: $180,130 (restricted and unrestricted)

Peri-Urban Agriculture in Africa

Evaluating economic externalities of agriculture such as soil-nutrient depletion, water pollution, health impacts through pesticides, and displacement of soil by erosion and sedimentation.

Budget 2001: $143,065 (restricted and unrestricted)

Sustainable Use of Shallow Groundwater in *Dambos* for Smallholder Agriculture, Southern Africa

Examining the long-term sustainability and productivity of the exploitation of low lying shallow groundwater aquifers in Zimbabwe and other Southern African countries.

Budget 2001: $80,500 (unrestricted)

Appropriate Smallholder Technologies for South Africa

Identifying technologies, such as treadle pumps and bucket and drip kits, that are appropriate to the South African smallholder context.

Budget 2001: $70,750 (unrestricted)

Sustainable Waste Management, Ghana

Increasing awareness among municipal and national authorities for an improved rural-urban nutrient cycle by identifying recycling options for organic waste stream products that are economically and socially acceptable, sustainable, and that benefit small farmers and the environment.

Budget 2001: $65,370 (restricted and unrestricted)

Theme 3: Sustainable Groundwater Management

IWMI-Tata India Water Research Program

Collaborative research to develop policy recommendations for sustainable use of groundwater and other water resources in India.

Budget 2001: $503,870 (restricted and unrestricted)

Rootzone Salinity Management, Pakistan

Evaluating strategies to control salinity levels in soils and groundwater so that the negative impacts on irrigated agricultural production are minimized.

Budget 2001: $110,900 (restricted and unrestricted)

Groundwater Management, South Africa

Assessing the groundwater economy and ecology in the Olifants Basin.

Budget 2001: $61,750 (unrestricted)

Secondary Salinization, Pakistan

Evaluating the extent of secondary salinization occurring in Pakistan, modeling the time frame for undesirable conditions to develop, and assessing the risk in different agro-ecological zones.

Budget 2001: $60,700 (unrestricted)

Groundwater Recharge and Conjunctive Management of Surface Water and Groundwater Supplies, India

Identifying promising strategies for groundwater recharge; developing and testing methods of controlling waterlogging and salinity through effective conjunctive management of surface water and groundwater supplies; building a better understanding of groundwater management in different hydrogeological and social conditions.

Budget 2001: $56,850 (unrestricted)

Theme 4: Water Resources Institutions and Policies

Effectiveness of Water Resources Management

Developing and supporting the implementation of policies and institutional strengthening programs that will lead to improved management of water used in agriculture.

Budget 2001: $744,300 (restricted and unrestricted)

Studies in Pro-Poor Interventions in the Irrigation Sector in Asia

Identifying the pro-poor potential of interventions in the irrigation sector by evaluating the impact of past investments in irrigation development and management.

Budget 2001: $484,250 (restricted and unrestricted)

Institutional Support Systems for Water-short Basins

Developing practical policy guidelines for designing and strengthening support systems for local irrigation management.

Budget 2001: $231,335 (restricted and unrestricted)

Impact Assessment of Infrastructure Development on Poverty Alleviation

Assessing the impacts of infrastructural development on poverty alleviation in Sri Lanka and Pakistan, developing performance indicators to measure the impact of infrastructure projects.

Budget 2001: $210,710 (restricted and unrestricted)

Local Water Management in South Africa

Identifying methods to increase agricultural productivity of small-scale irrigation systems and developing improved institutional arrangements for productive, socially equitable and sustainable irrigation systems in the Northern Province of South Africa.

Budget 2001: $144,790 (restricted)

Institutional Arrangements for Improving Water Management, Central Asia

Evaluating water user associations in the three countries sharing the Ferghana Valley (Kyrgyzstan, Tajikistan and Uzbekistan), analyzing legal and institutional constraints to effective water management, and monitoring variables affecting water productivity and agricultural performance.

Budget 2001: $82,550 (unrestricted)

Theme 5: Water for Health and the Environment

Improving the Performance of Wastewater Irrigation in Peri-Urban Areas, Pakistan

Evaluating the health and economic impacts of using wastewater from the town of Faisalabad for irrigation; identifying opportunities for increasing the productivity of wastewater irrigation.

Budget 2001: $152,580 (restricted and unrestricted)

Wastewater Reuse in Agriculture, Vietnam

Examining the water management, environmental, and human health aspects of wastewater irrigation and identifying ways to maximize benefits while reducing risks.

Budget 2001: $142,000 (restricted and unrestricted)

System-Wide Initiative on Malaria and Agriculture (SIMA)

Uncovering the links between agricultural practices and malaria and identifying effective agriculture-based interventions.

Budget 2001: $97,750 (unrestricted)

Large-Scale Irrigation Systems and Malaria, Pakistan

Identifying water management options for controlling malaria in canal irrigation systems in Pakistan.

Budget 2001: $97,400 (restricted)

Malaria Risk Mapping, Sri Lanka

Developing a malaria risk map for Sri Lanka; exploring the utility of IWMI developed information technologies and products in malaria risk mapping and epidemic forecasting.

Budget 2001: $93,847 (restricted and unrestricted)

Agro-Ecosystem Management for Human Health, Sri Lanka

Determining the impact of different water management regimes, rehabilitation of canals, and cropping patterns on: vector breeding, availability of water for domestic purposes, and requirements for agrochemical inputs in the Uda Walawe Irrigation scheme.

Budget 2001: $92,100 (restricted and unrestricted)

Pre-Development Biodiversity Assessment of the Uda Walawe Irrigation Extension Project, Sri Lanka

Establishing a biodiversity inventory in the proposed command area of the Uda Walawe Extension Project to evaluate changes that occur during the process of development and in the settled irrigation phase of the project.

Budget 2001: $87,500 (restricted and unrestricted)

IWMI-Taiwan Collaborative Research on the Impact of Irrigation on Water Resources Systems

Evaluating irrigation performance and environmental functions of paddy rice cultivation in Sri Lanka, Taiwan and Japan

Budget 2001: $71,500 (restricted and unrestricted)

Irrigation and Domestic Water Supply and Sanitation, Pakistan

Identifying and testing community-based methods to improve water supply and sanitation and reduce diarrheal disease.

Budget 2001: $68,880 (restricted and unrestricted)

Irrigation and Wetlands, Sri Lanka

Analyzing data on water flows, water quality, flora, fauna and resources use in the Kirindi Oya Irrigation Scheme and wetlands of the Bundala National Park.

Budget 2001: $ 63,150 (unrestricted)

Water Management for Malaria Control in Tank Cascade Systems

Understanding the links between vector breeding and tank cascade systems and identifying options for control.

Budget 2001: $58,000 (restricted and unrestricted)

Headquarters

Office of the Director General: Prof. Frank Rijsberman – Director General, Nanda Abeywickrama - Special Advisor to Director General, Himani Elangasinghe, Mirani Heyzer, Suzanne Samarawickrema

Finance & Administration: David Governey - Deputy Director General (Operations), Gamini Halvitige - Financial Controller, Sepala Amarasuriya - Senior Manager (Human Resources), Ajith Piyaratne - Manager (Building Services & Transport), Daya Samaraweera - Manager (Administrative Office), Lal Abeykoon, Selva Arockiam, T. Bahar, Y. Costa, Sujatha Dassanayake, Anusha De Silva, Kumara Dharmasiri, Iresha Dharmawardhana, Ravi Dissanayake, D. Gunasekera, Sunil Jayatillake, Thusitha Jayatilleke, Mahilal Jayawardena, Anthony Joseph, Hilda Joseph, Mahinda Karandawatte, Chanchala Kariyawasam, Upali Karunanayake, S Krishnarajah, Shantha Kumara, Shahnaz Makawita, Kapila Pathiraja, P. Pathirana, Ajith Perera, K. Punchibanda, S. Pushparajah, Priyanka Rajakaruna, Kamani Rajanayake, Tissa Rajanayake, M. Ramraj, Ajith Ratnayake, P. Rezel, Hemantha Samarakoon, Ranjith Samarakoon, S. M. B. Seneviratne, Sriyani Seneviratne, Nihal Silva, N. Sri Ranjithsinghe, W. Upali, Shanthi Weerasekera, Yvonne Weerasinghe,

Computer Services: Erhard Haniffa - Manager (Computer Services), Ashra Fernando, R. Jayasinghe, Santha Marasinghe, Nirudha Perera, David Van Eyck, Ranjith Wickremasinghe

Communications & Donor Relations Office: Michael Devlin-Head of Communications Donor Relations Office, Nimal Fernando – Manager (Publications Unit), N. U. Yapa - Head Librarian, Natalia Abeynayake, Pavithra Amunugama, N. Attanayake, Sarah Carriger, Zareena Chunchie, Manik De Alwis, Ramya De Silva, Sarath Edirimanne, Shyamine Faleel, Sumith Fernando, Anila Hettiarachchi, Dilrukshi Hewagama, Kithsiri Jayakody, D. C. Karunaratne, Kingsley Kurukulasuriya, Nilmini Matthysz, Kshalini Nonis, Nihal Perera, Shanthi Sri Nammuni, Surendra Wegodapola, Ajith Wijayaratne

Regional Office for Asia

Principal Researchers: Ian Makin - Regional Director*, Dr. David Molden - Leader of Integrated Water Management Theme*, Dr. Felix Amerasinghe, Dr. Randolph Barker, Dr. Hammond Murray-Rust, Dr. R. Sakthivadivel, Dr. Willem van der Hoek - Leader of Water, Health & Environment Theme*

Senior Researchers: Dr. Peter Droogers, Dr. Intizar Hussain, Dr. Geoff Kite, Dr.Yutaka Matsuno, Dr. Hilmy Sally, Dr. Chris Scott

Researchers: Charlotte De Fraiture, Izhar Hunzai

Post Doctoral Scientists / Associate Experts: Dr. Shrinivas Badiger**, Dr. Eline Boelee, Jacobijn Van Etten, Ronald Loeve, Dr. Madhusudan Bhattarai**, Dr. Jinxia Wang**

Research Associates: Dr. Upali Amarasinghe, Yann Chemin, Lalith Dassenaike, Dilkushi De Alwis, Manju Hemakumara, Gayathree Jayasinghe, K. Jinapala, Eveline Klinkenberg - Consultant in Malaria Risk Mapping, Dr. S. M. F. Marikkar - Consultant in Irrigation System Performance, Dr. Liqa Raschid Sally - Consultant in Water and Health, Dr. Madar Samad

Research Staff: Noel Aloysius, B. Ariyaratne, M. Dayananda, Dhammika De Silva, Indrajith Gamage, Janitha Godamuduna, Sepali Goonaratne, Sarath Gunasinghe, S. Karunaratne, Shalini Kumaresan, Sarath Lionalratne, Veronica Lumanauw, Lal Muthuwatta, David Paul, L. Perera, S. Piyankarage, M. Piyaratne, D. Premachandra, Sushilla Rajamanie, D. Ranasinghe, Mala Ranawake, Alankara Ranjith, P. Somaratne, Sunil Thrikawala, Parakrama Weligamage - Consultant in Irrigation Database Management

Regional Office for Pakistan, Central Asia and the Middle East

Principal Researchers: Dr. Vilma Horinkova - Regional Director

Post Doctoral Scientists / Associate Experts: Dr. Mohammed Mainuddin**, Dr. Katsuyuki Shimizu**, Paul Vehmeyer

Research Associates: Dr. Muhammad Aslam, Dr. Shafqat Ejaz, Jeroen Ensink - Consultant in Water and Health, Dr. Nadeem Gill, Zaigham Habib, Mehmood Hassan, Nathaly Herrel - Consultant in Malaria and Irrigation, Dr. Waqar Jehangir, Iqbal Mirza, Dr. Asad Qureshi, Saeed Rehman, Dr. M. S. Shafique - Consultant in Salinity Management, Dr. Koos de Voogt - Consultant in Groundwater Management

Research Staff: Mobin Ahmed, Tabraiz Ahmed, Nazim Ali, Samia Ali, Muhammad Amin, Dr. Muhammad Ashraf, Mohammad Aslam, Abdul Hamid, Shabana Hamid, Anwar Iqbal, Abdul Khan, Asim Khan, Mohammad Khan, Bakhshal Lashari, Khalid Mehmood, Mohammad Memon, Munawar Memon, Zafar Mirza, Muhammad Mukhtar, Sarfraz Munir, Hafiz Nafees, Asma Saleem, Fouzia Shahin, Shabana Shaukat, Niaz Sial, Salman Siddiqui, Zubair Tahir, Ghulam Talpur, Kaleem Ullah, Waheed Zaman

Research Support: Muhammad Abid, Ahmad Ali, Amir Ali, Muhammad Amjid, Yasir Arafat, Muhammad Arshad, Umer Draz, Umer Hayat, Asghar Hussain, Manzoor Hussain, Najaf Khan, Anwar Iqbal, Tariq Mahmood, Shahzad Mehmood, Syed Munawar, Tipu Naveed, Tariq Nazeer, Farah Sattar, Khalid Siddiqui, Mahmooda Tabbassum, Nyla Tabassum

Finance & Administration: Akhtar Sandhu – Manager of Finance & Administration Division, Faisal Abdullah, Moghis Ahmed, Tabrez Ahmed, Siddique Akbar, Shahnaz Akhtar, Qurban Ali, Yousaf Amin, Muhammad Anwar, Zaheer Anwer, Muhammad Arshad, Muhammad Asghar, Masih Ashraf, Mohammad Aslam, Masih Bashir, Eric Benjamin, Mohsin Dar, Mashooque Deeshak, Nadeem George, Khan Ihsanullah, Mohammad Iqbal, Mohammad Jehangir, Abdul Kashif, Mohammad Khan, Muhammad Khan, Santoosh Kumar,

*Position as of January, 2001 **As of February, 2001

Muhammad Manshah, Akram Masih, Ashraf Masih, Bashir Masih, Nazar Masih, Wilson Masih, Yaqoob Masih, Sultan Mehmood, Muhammad Mughal, Ishaq Muhabbat, Masih Nazar, Pervaiz Ramzan, Muhammad Raza, Muhammad Saleem, Mohammad Sameeullah, Mohammad Shafiq, Changaiz Sunny, Riaz Wicky

Information & Communications: Muhammad Saeed, Sofiya Saeed

Regional Office for India

Principal Researchers: Dr. Tushaar Shah - Leader of Sustainable Groundwater Management Theme & Acting Regional Director*

Nepal

Researcher: K. C. Prasad, Research Coordinator

Regional Office for Africa

Principal Researchers: Dr. Douglas Merrey - Regional Director

Senior Researchers: **Kenya:** Dr. Clifford Mutero, Dr. Herbert Blank

Researchers: **South Africa:** Dr. Abdul Kamara**, Dr. Barbara Van Koppen, Dr. Marna de Lange, Herve Levite, Dr. Mutsa Masiyandima
Senegal: Pierrick Fravel
Côte d'Ivoire: Dr. Wilfried Hundertmark

Sub-regional Office, Ghana (As of 1 April, 2001)

Senior Researcher: Dr. Pay Drechsel

Post Doctoral Fellow: Dr. Olufunke Cofie

Research Assistants: Lucy Gyiele, Philip Amoah

Regional Office for Southeast Asia (As of 1 April, 2001)

Principal Researchers: Jayatissa Bandaragoda – Regional Director, Dr. Frits Penning de Vries - Theme Leader, Sustainable Smallholder Land and Water Management Systems

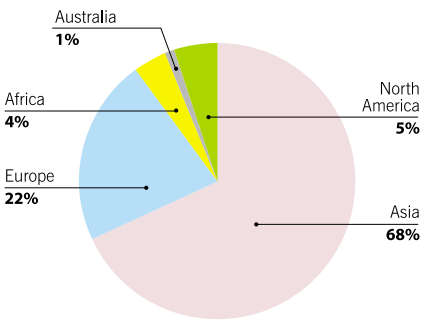
Senior Researchers: Dr. Rod Lefroy, Dr. Amado Maglinao, Dr. Gadsaraporn Wannitikul

Research Associates: Suraphol Chandrapatya - Head, Host Government Relations

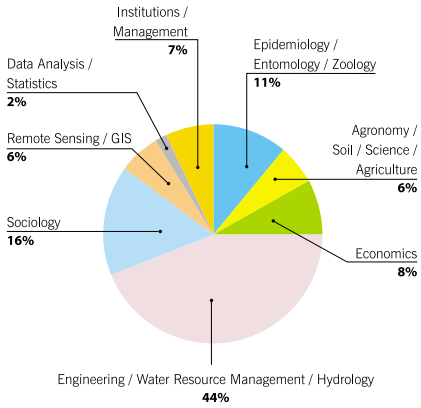
Research Assistants: Rungnadhee Phonkarm, Lakana Sangkhakorn, Wanippa Soda

Support Staff: Charoensidhi Vipavee - Manager (Finance & Administration), Jutima Anumatratchakit, Jirapar Boonyasurakul, Tanadol Compo, Pornchai Luechatmatikul, Narin Peeraoranum, Naiyana Puranachoti, Darakul Srichoorom, Pornchai Srisuwatjaree

IWMI Research Staff
(by Nationality – 2000)



IWMI Research Staff
(by Discipline – 2000)



IWMI Research Report Series:

This series is IWMI's flagship publication. The priority for this series is to present generic thinking and perspectives culled from IWMI research. These reports are validated through a process similar to that of international scientific and research journals. Reports are peer-reviewed by a panel of international experts, covering all aspects of water and land management.

An editorial board is being finalized for 2001. This panel includes senior scientists who have achieved renown in their field. These men and women will help guide the direction of IWMI's work and ensure that IWMI research adheres to the highest scientific standards.

1. **Abernethy, C. L.; Sally, H.; Lonsway, K.; Maman, C. 2000.** Farmer-based financing of operations in the Niger Valley irrigation schemes. Colombo, Sri Lanka: IWMI. v, 36p. (IWMI research report 37)
2. **Vermillion, D. L.; Samad, M.; Pusposutardjo, S.; Arif, S. S.; Rochdyanto, S. 2000.** An assessment of the Small-Scale Irrigation Management Turnover Program in Indonesia. Colombo, Sri Lanka: IWMI. v, 36p. (IWMI research report 38)
3. **Keller, A.; Sakthivadivel, R.; Seckler, D. 2000.** Water scarcity and the role of storage in development. Colombo, Sri Lanka: IWMI. v, 16p. (IWMI research report 39)
4. **Lacroix, M.; Kite, G.; Droogers, P. 2000.** Using datasets from the Internet for hydrological modeling: An example from the Küçük Menderes Basin, Turkey. Colombo, Sri Lanka: IWMI. v, 30p. (IWMI research report 40)
5. **Scott, C. A.; Zarazúa, J. A.; Levine, G. 2000.** Urban wastewater reuse for crop production in the water-short Guanajuato River Basin, Mexico. Colombo, Sri Lanka: IWMI. v, 34p. (IWMI research report 41)
6. **Kite, G.; Droogers, P. 2000.** Comparing estimates of actual evapotranspiration from satellites, hydrological models, and field data: A case study from Western Turkey. Colombo, Sri Lanka: IWMI. v, 32p. (IWMI research report 42)
7. **Kite, G.; Droogers, P. 2000.** Integrated basin modeling. Colombo, Sri Lanka: IWMI. v, 30p. (IWMI research report 43)
8. **Hussain, I.; Marikar, F.; Jehangir, W. 2000.** Productivity and performance of irrigated wheat farms across canal commands in the Lower Indus Basin. Colombo, Sri Lanka: IWMI. v, 28p. (IWMI research report 44)
9. **Shah, T.; Alam, M.; Kumar, M. D.; Nagar, R. K.; Singh, M. 2000.** Pedaling out of poverty: Social impact of a manual irrigation technology in South Asia. Colombo, Sri Lanka: IWMI. vi, 36p. (IWMI research report 45)

Working Papers:

Working papers document other important aspects of IWMI's research. These are not peer-reviewed, but present useful concepts and findings from the Institute's work in many countries.

1. **de Voogt, K.; Kite, G.; Droogers, P.; Murray-Rust, H. 2000.** Modeling water allocation between wetlands and irrigated agriculture: Case study of the Gediz Basin, Turkey. Colombo, Sri Lanka: IWMI. xi, 51p. (IWMI working paper 1)
2. **Kite, G. 2000.** Developing a hydrological model for the Mekong Basin: Impacts of basin development on fisheries productivity. Colombo, Sri Lanka: IWMI. v, 141p. (IWMI working paper 2)
3. **Tren, Richard; Schur, Michael. 2000.** Olifants River Irrigation Schemes. Colombo Sri Lanka: IWMI, iv, 32p (IWMI working paper 3)
4. **Shah, T.; Hussain, I.; Saeed ur Rehman. 2000.** Irrigation management in Pakistan and India: Comparing notes on institutions and policies. Colombo, Sri Lanka: IWMI. v, 15p. (IWMI working paper 4)

Latin America Series:

1. **de Fraiture, C.; Rubiano, J.; Alvarez, C. 2000.** Uso real y potencial del agua en la cuenca del rio Cabuyal, Colombia. Mexico City, DF, Mexico: IWMI. Mexico Program. xvi, 56p. (IWMI serie Latinoamericana no.12)
2. **Kloezen, W. H. 2000.** Viabilidad de los arreglos institucionales para el riego después de la transferencia del manejo en el Distrito de Riego Alto Río Lerma, México. [The viability of institutional arrangements after irrigation management transfer in the Alto Rio Lerma Irrigation District, Mexico] Mexico, D.F., Mexico: IWMI. xviii, 88p. (IWMI, serie Latinoamericana, no.13)

3. **Buechler, S.; Martelo, E. Z. (Eds.) 2000.** Género y manejo del agua y tierra en communidades rurales de Mexico. Mexico City, DF, Mexico: IWMI. Mexico Program; Colegio de Postgraduados. xiv, 202p. (IWMI serie Latinoamericana no.14)

4. **Flores-Lopez, F. J.; Scott, C. A. 2000.** Superficie agricola estimada mediante analisis de imagenes de satelite en Guanajuato, Mexico. [Estimating agricultural areas using satellite imagery in Guanajuato, Mexico] Mexico, DF., Mexico: IWMI. xvii, 43p. (IWMI serie Latinoamericana no.15)

5. **Wester, P.; Cornish, G.; Ramirez-Calderon, J. J. 2000.** Determinacion de las prioridades de mantenimiento en los sistemas de riego transferidos: a aplicacion del procedimiento MARLIN en el Distrito de Riego Alto Rio Lerma, Mexico. [Determining maintenance priorities in transferred irrigation systems: The application of the MARLIN procedure in the Alto Rio Lerma Irrigation District, Mexico] Mexico, D.F., Mexico: IWMI. xvii, 57p. + annexes. (IWMI serie Latinoamericana no.16)

6. **Maranon-Pimentel, B.; Wester, P. 2000.** Respuestas institucionales para el manejo de los acuiferos en la Cuenca Lerma-Chapala, Mexico. Institutional response for aquifer management in the Lerma-Chapala Basin, Mexico] Mexico, D.F., Mexico: IWMI. xv, 53p. (IWMI serie Latinoamericana no.17)

7. **Rodriguez-Betancourt, R.; Gonzalez-Aguirre, J. 2000.** El manejo de los recursos hidricos en Venezuela. [Water management in Venezuela] Mexico, DF., Mexico: IWMI. xiii, 40p. (IWMI serie Latinoamericana no.18)

8. **Silva-Ochoa, P. (Ed.) 2000.** Unidades riego: La otra mitad del sector agricola bajo riego en Mexico. [Irrigation "unidades": The other half of the irrigated agriculture sector] Mexico, D.F., Mexico: IWMI. xvi, 92p. (IWMI serie Latinoamericana no.19)

9. **Scott, C. A.; Wester, P.; Maranon-Pimental, B. (Eds.) 2000.** Asignacion, productividad y manejo de recursos hidricos en cuencas. [Allocation, management and productivity of water resources in river basins] Mexico, DF., Mexico: IWMI. xix, 234p. (IWMI serie Latinoamericana no.20)

Pakistan Reports

1. **Brewer, J. D.; Sharma, K. R. 2000.** Conjunctive management in the Hardinath Irrigation System, Nepal. Lahore, Pakistan; Griffith, NSW, Australia: IWMI. Pakistan National Program; CSIRO. vii, 53p. (IWMI Pakistan report no.R-94)

2. **Raju, K. V.; Brewer, J. D. 2000.** Conjunctive management, North Bihar, India. Lahore, Pakistan; Griffith, NSW, Australia: IWMI. Pakistan National Program; Pakistan Council of Research Water Resources (PCRWR); CSIRO. ix, 70p. (IWMI Pakistan report no.R-95)

3. **Skogerboe, G. V. 2000.** Groundwater salinity in the Colorado River Basin. Lahore, Pakistan; Griffith, NSW, Australia: IWMI. Pakistan National Program; Pakistan Council of Research Water Resources (PCRWR); CSIRO. ix, 75p. (IWMI Pakistan report no.R-96)

4. **Feenstra, S.; Jabbar, A.; Masih, R.; Jehangir, W. A. 2000.** Health hazards of pesticides in Pakistan. Islamabad, Pakistan; Lahore, Pakistan: Pakistan Agricultural Research Council; IWMI. Pakistan National Program. iii, 20p. (IWMI Pakistan report no.100)

5. **Feenstra, S.; Hussain, R.; van der Hoek, W. 2000.** Prevalence of intestinal parasites in the Southern Punjab, Pakistan. Lahore, Pakistan: IWMI. Pakistan National Program. iii, 27p. (IWMI Pakistan report no.101)

6. **Chemin, Y.; Mobin ud Din Ahmad. 2000.** Estimating evaporation using the surface energy balance model (SEBAL): A manual for NOAA-AVHRR in Pakistan. Lahore, Pakistan: IWMI. Pakistan National Program. i, 27p. (IWMI Pakistan report no.R-102)

7. **Khan, A. R.; Muhammad, S. 2000.** A spatio-temporal analysis of rainfall in the canal command areas of the Indus Plains. Lahore, Pakistan: IWMI. Pakistan National Program. xi, 35p. (IWMI Pakistan report no.R-104)

8. **Starkloff, R. 2000.** Farmers' perceptions of the short-term impacts of the social mobilization of water user organizations in LBOD, Sindh. Lahore, Pakistan: IWMI. Pakistan National Program. x, 63p. (IWMI Pakistan research report no.R-105)

9. **Wahaj, R.; Vincent, L.; Prathapar, S. A. 2000.** Farmers' management responses to the gap between supply and demand of canal water. Lahore, Pakistan: IWMI. Pakistan National Program. ii, 18p. (IWMI Pakistan research report no.R-106)

10. **Feenstra, S.; Hussain, R.; van der Hoek, W. 2000.** Health risks of irrigation with untreated urban wastewater in the Southern Punjab, Pakistan. Lahore, Pakistan: IWMI. Pakistan National Program; Institute of Public Health. v, 13p. (IWMI Pakistan report no.107)

11. **Mirza, Z. I.; Mehmood Ul Hassan; Bandaragoda, D. J. 2000.** From state to jointly managed irrigation systems: Social mobilization and management transfer guidelines for large canal systems. Lahore, Pakistan: IWMI. Pakistan National Program. vii, 44p. (IWMI Pakistan research report no.R-108)

South Africa Working Papers:

1. **Mpahlele, R. E.; Malakalaka, T. M.; Hedden-Dunkhorst, B. 2000.** Characteristics of smallholder irrigation farming in South Africa: A case study of the Arabie-Olifants River Irrigation Scheme. Colombo, Sri Lanka: IWMI. x, 32p. (South Africa working paper no.3)

Journal Articles

1. **Barker, R.; Scott, C. A.; de Fraiture, C.; Amarasinghe, U. 2000.** Global water shortages and the challenge facing Mexico. ***International Journal of Water Resources Development,*** 16(4):525-542.
2. **Bastiaanssen, W. G. M.; Molden, D. J.; Makin, I. W. 2000.** Remote sensing for irrigated agriculture: Examples from research and possible applications. ***Agricultural Water Management,*** 46(2):137-155.
3. **Bastiaanssen, W. G. M. 2000.** Satellite observations of international river basins for all. ***In International Archives of Photogrammetry and Remote Sensing,*** 33(B6):319-331.
4. **Bastiaanssen, W. G. M. 2000.** SEBAL based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey. ***Journal of Hydrology,*** 229(1-2):87-100.
5. **de Fraiture, C.; Molden, D.; Amarasinghe, U.; Makin, I. 2000.** Podium: Projecting water supply and demand for food production in 2025. ***Geophysical Research Abstracts,*** Vol.2:
6. **de Voogt, K.; Kite, G.; Droogers, P.; Murray-Rust, H. 2000.** Modelling water allocation between a wetland and irrigated agriculture in the Gediz Basin, Turkey. ***International Journal of Water Resources Development,*** 16(4):639-650.
7. **Droogers, P.; Bastiaanssen, W. G. M.; Beyazgul, M.; Kayam, Y.; Kite, G. W.; Murray-Rust, H. 2000.** Distributed agro-hydrological modeling of an irrigation system in Western Turkey. ***Agricultural Water Management,*** 43(2):183-202.
8. **Droogers, P. 2000.** Estimating actual evapotranspiration using a detailed agro-hydrological model. ***Journal of Hydrology,*** 229(1-2):50-58.
9. **Droogers, P.; Bastiaanssen, W. G. M. 2000.** Evaporation estimates using a combined hydrological model and remote sensing approach. ***Geophysical Research Abstracts,*** Vol.2:
10. **Droogers, P.; Kite, G.; Murray-Rust, H. 2000.** Use of simulation models to evaluate irrigation performance including water productivity, risk and system analyses. ***Irrigation Science,*** 19(3):139-145.
11. **Gallopin, G. C.; and Rijsberman, F. R. 2000.** Three global water scenarios. ***International Journal of Water.*** 1(1):16-40
12. **HRH The Prince of Orange; Rijsberman, F. R. 2000.** Summary report of the 2nd World Water Forum: From vision to action. ***Water Policy,*** 2(6):387-395.
13. **Kite, G. W.; Droogers, P.** (Eds.) **2000.** Comparing evapotranspiration estimates from satellites, hydrological models and field data. ***Journal of Hydrology,*** 229(1-2):3-18.
14. **Kite, G.W. 2000.** Using a basin-scale hydrological model to estimate crop transpiration and soil evaporation. ***Journal of Hydrology,*** 229(1-2):59-69.
15. **Konradsen, F.; van der Hoek, W.; Amerasinghe, P. H.; Amerasinghe, F. P.; Perera, D. 2000.** A village treatment center for malaria: Community response in Sri Lanka. ***Social Science and Medicine,*** 50:879-889.
16. **Levine, G.; Ko Hai Sheng; Barker, R. 2000.** The evolution of Taiwanese irrigation: Implications for the future. ***Water Resources Development,*** 16(4):497-510.
17. **Michael, M. G.; Bastiaanssen, W. G. M.A. 2000.** A new simple method to determine crop coefficients for water allocation planning from satellites: Results from Kenya. ***Irrigation and Drainage Systems,*** 14(3):237-256.
18. **Mutero, C. M.; Blank, H.; Konradsen, F.; van der Hoek, W. 2000.** Water management for controlling the breeding of Anopheles mosquitoes in rice irrigation schemes in Kenya. ***Acta Tropica,*** 76:253-263.
19. **Raju, K. V.; Shah, T. 2000.** Revitalisation of irrigation tanks in Rajasthan. ***Economic and Political Weekly,*** 25(23):1930-1936.
20. **Renault, D. 2000.** Aggregated hydraulic sensitivity indicators for irrigation system behavior. ***Agricultural Water Management,*** 43(2):151-171
21. **Renault, D.; Hemakumara, M.; Molden, D. 2000.** Importance of water consumption by perennial vegetation in irrigated areas of the humid tropics: Evidence from Sri Lanka. ***Agricultural Water Management,*** 46(3):215-230.

22. **Renault, D.; Wallender, W. W. 2000.** Nutritional water productivity and diets. ***Agricultural Water Management,*** 45(3):275-296.

23. **Renault, D. 2000.** Operational sensitivity of irrigation structures. ***Journal of Irrigation and Drainage Engineering,*** 126(3):157-162.

24. **Sarwar, A.; Bastiaanssen, W. G. M.; Boers, T. M.; van Dam, J. C. 2000.** Evaluating drainage design parameters for the Fourth Drainage Project, Pakistan by using SWAP model: Part I - calibration. ***Irrigation and Drainage Systems,*** 14(4):257-280.

25. **Sarwar, A.; Feddes, R. A. 2000.** Evaluating drainage design parameters for the Fourth Drainage Project, Pakistan by using SWAP model: Part II - modeling results. ***Irrigation and Drainage Systems,*** 14(4):281-299.

26. **Shah, T. 2000.** Mobilising social energy against environmental challenge: Understanding the groundwater recharge movement in Western India. ***Natural Resources Forum,*** 24(3):197-209.

27. **Wahid, M. A.; Mehmood Ul Hassan. 2000.** Case studies: Case 1 - Union is strength: Participatory development experiences of Hakra 4-R Distributary farmers in Pakistan's Southern Punjab. ***Canadian Journal of Development Studies,*** 21(Special Issue):621-624.

Chapters in Monographs/Books:

1. **Ahlers, R. 2000.** Gender issues in irrigation. In Tortajada, C. (Ed.), Women and water management: The Latin American Experience. New Delhi, India: OUP. pp.203-216.

2. **Bastiaanssen, W. G. M.; Perry, C. J. 2000.** Earth observation demands for improved water resources management. In Verstraete, M. M.; Menenti, M.; Peltoniemi, J. (Eds.), Observing land from space: Science, customers and technology. Dordrecht, Netherlands: Kluwer Academic Publishers. pp.105-117.

3. **Brewer, J. D.; Sakthivadivel, R. 2000.** The impact of participatory irrigation management on performance of maintenance: A Maharashtra case. In Joshi, L. K.; Hooja, R. (Eds.), Participatory irrigation management: Paradigm for the 21st century - Volume 2. Jaipur, India: Rawat Publications. pp.628-651.

4. **Habib, Z. 2000.** Resource conservation and civil society: Water and food security in Pakistan. In Molinga, P. P. (Ed.), Water for food and rural development: Approaches and initiatives in South Asia. New Delhi, India: Sage Publications. 182-196.

5. **Kite, G.; Pietroniro, A. 2000.** Remote sensing of surface water. In Schultz, G. A.; Engman, E. T. (Eds.), Remote sensing in hydrology and water management. Berlin, Germany: Springer. pp.217-238.

6. **Sally, H. 2000.** Mode d'exploitation et de gestion: Agriculture irriguee ou agriculture de crue et de decrue. In Groupe d'Experts sur les Plaines d'Inondation Saheliennes (GEPIS), Vers une gestion durable des plaines d'inondation Saheliennes. Cambridge, UK: UICN. pp.81-84.

7. **Sally, L. 2000.** Etudes d'impact sur l'environnement. In Groupe d'Experts sur les Plaines d'Inondation Saheliennes (GEPIS), Vers une gestion durable des plaines d'inondation Saheliennes. Cambridge, UK: UICN. pp.32-35.

8. **Shah, T. 2000.** Building and managing knowledge institutions: Lessons of India's experience. In Reddy, K. P.; Singh, K. (Eds.), Designing and managing rural development organisations. New Delhi, India: Oxford & IBH Publishing Co. Pvt. Ltd. pp.31-63.

9. **Shah, T. 2000.** Water against poverty: Livelihood-oriented water resources management. In Molinga, P. P. (Ed.), Water for food and rural development: Approaches and initiatives in South Asia. New Delhi, India: Sage Publications. pp.38-69.

10. **Van Koppen, B. 2000.** Gendered water and land rights in rice valley improvement, Burkina Faso. In Bruns, B. R.; Meinzen-Dick, R. S. (Eds.), Negotiating water rights. London, UK: Intermediate Technology Publications. pp.83-111

Papers Presented at Conferences/Workshops/Seminars:

1. **Barker, R.; Molden, D. 2000.** The Asian rice economy in transition. Paper presented at the Symposium on Rice Research and Production in the 21st Century: A symposium honoring Dr Robert F. Chandler Jr., 15-17 June 2000, Ithaca, Usa, Cornell University.

2. **Barker, R. . 2000.** Global water: An essential yet finite natural resource: Availability, uses, and needs. Paper presented at the Mini Symposium on Water, Grasmere, England, 27-30 March 2000.

3. **Barker, R.; Molden, D. 2000.** Global water shortages, alternatives for increasing water productivity, and implications for China. Paper presented at the Water Policy Forum, 1 June 2000, CCAP, China.

4. **Barker, R. 2000.** Toward integrated water resource management. Paper presented at the 6th General Assembly of the Asia-Pacific Association of Agricultural Research Institutions (APAARI) and Expert Consultation on Strategies for Implementing APAARI Vision 2025: Agricultural Research Development, Chiang Rai, Thailand, 8-10 November 2000.

5. **Garces-Restrepo, C.; Mora, L. A. 2000.** Agua para la seguridad alimentaria y el desarrollo rural en el contexto Suramericano. [Water for food security and rural development in the South American context] Paper presented at Conferencia Internacional AGUA 2000, Cali, Octubre 19 al 21 del 2000. 12p.

6. **Samarasinghe, S. A. P; Sakthivadivel, R.; Sally, H. 2000.** Sustainable management of the Deduru Oya River Basin, Sri Lanka: A case study of institutions, organizations and actors. Paper presented at the South Asia Regional Workshop on River Basin Management, Colombo, Sri Lanka, 17-19 July 2000.

7. **Shah, T.; Alam, M.; Kumar, M. D.; Nagar, R. K.; Singh, M. 2000.** Pedal pump and the poor: Social impact of a manual irrigation technology in South Asia. Paper presented at the Workshop on Poverty, Gender and Water in South Asia, Ahmedabad, India, Organised by IWMI, Colombo, and Gujarat Institute of Development Research, Ahmedabad, 10-11 August 2000. 38p.

8. **Shah, T. 2000.** Wells and welfare in the Ganga Basin: Essay on public policy and private initiative. Paper presented at the Workshop on Poverty, Gender and Water in South Asia, Ahmedabad, India, Organised by IWMI, Colombo, and Gujarat Institute of Development Research, Ahmedabad, 10-11 August 2000. 35p.

9. **Van Koppen, B. 2000.** Gender and poverty dimensions of irrigation. Keynote address Micro2000 Conference, Cape Town.

Miscellaneous Publications:

1. **Bandaragoda, D. J. 2000.** A framework for institutional analysis for water resources management in a river basin context. Colombo, Sri Lanka: IWMI. ii, 46p.

2. **Barker, R.; van Koppen, B.; Shah, T. 2000.** A global perspective on water scarcity and poverty: Achievements and challenges for water resource management. Colombo, Sri Lanka: IWMI. 16p.

3. **IWMI; Turkey. General Directorate of Rural Services. 2000.** Irrigation in the basin context: The Gediz study. Colombo, Sri Lanka: IWMI. xv, 105p.

4. **IWMI. 2000.** Research contribution to the World Water Vision. Colombo, Sri Lanka: IWMI. 26p.

5. **Konradsen, F.; Amerasinghe, F. P.; van der Hoek, W.; Amerasinghe, P. H. 2000.** Malaria in Sri Lanka: Current knowledge on transmission and control. Colombo, Sri Lanka: IWMI. xiv, 77p.

6. **Mirza, Z. I.; Saeed, S.** (Comp.) **2000.** Institutional reforms in irrigation sector of Punjab, Pakistan: Proceedings of Workshop held at Faisalabad Serena on 10-11 February 2000. Lahore, Pakistan: IWMI; Punjab Irrigation and Drainage Authority. xi, 91p.

7. **Mirza, Z. I.; Saeed, S.** (Comp.) **2000.** Institutional reforms in irrigation sector of Punjab, Pakistan: Proceedings of Workshop held at Faisalabad Serena on 10-11 February 2000. Lahore, Pakistan: IWMI; Punjab Irrigation and Drainage Authority. xiii, 103p.

8. **Raschid-Sally, L. 2000.** Arsenic contamination of groundwater in Bangladesh. Colombo, Sri Lanka: IWMI. iii, 31p. (IWMI discussion paper)

9. **Saeed, S.; Khan, M. I.** (Eds.; Comp.) **2000.** Summary of activities: Research reporting day, November 16, 2000. Lahore, Pakistan: IWMI Pakistan Program. iii, 74p.

10. **Samad, M.; Wijesekera, N. T. S.; Birch, A.** (Eds.) **2000.** Status and future direction of water research in Sri Lanka: Proceedings of the National Conference held at the BMICH, Colombo, Sri Lanka, 4-6 November, 1998. Colombo, Sri Lanka: IWMI. xv, 257p.

11. **Shah, T.; Molden, D.; Sakthivadivel, R.; Seckler, D. 2000.** The global groundwater situation: Overview of opportunities and challenges. Colombo, Sri Lanka: IWMI. v, 21p.

12. **Sri Lanka National Water Partnership; LIFE-WRU; WRS; IWMI. 2000.** Water vision 2025 Sri Lanka. Colombo, Sri Lanka: LIFE. 14p.

13. **van Koppen, B. 2000.** From bucket to basin: Managing river basins to alleviate water deprivation. Colombo, Sri Lanka: IWMI. ix, 34p.

14. **Waheed uz Zaman.** (Comp.) **2000.** Institutional reforms in irrigation sector of Balochistan, Pakistan: Proceedings of the Workshop held at Dera Murad Jamali on 30 to 31 October 1999. Lahore, Pakistan; Balochistan, Pakistan: IWMI. Pakistan National Program; Balochistan Irrigation and Drainage Authority (BIDA) v, 76p.