Annual Report 1997

International Irrigation Management Institute

Selected Research Highlights

#038238

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ISSN 1017-5954
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Credits

Scientific sources: Geoff Kite and Peter Droogers (*Basin water resources management in Turkey*); David Molden, R. Sakthivadivel, Mona El-Kady, and Zhongping Zhu (*Use and productivity of the Nile water in Egypt*); W. G. M. Bastiaanssen, S. Thiruvengadachari, R. Sakthivadivel, and David Molden (*Estimating the productivity of land and water at the Bhakra irrigation system in India*); Douglas J. Merrey and Douglas L. Vermillion (*Water management in the twenty-first century*).

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Publications Manager: Nimal A. Fernando; *Printer:* Sumathi Book Printing (Pvt) Ltd.

Cover images: Geoff Kite and Peter Droogers.

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Foreword

The 1997 annual report reflects a significant change in the focus of IIMI's research. While retaining and indeed deepening our research in irrigation, we have also broadened our research in two important directions. First, we are conducting research on the *multiple uses of water*, especially on the close interrelationships between irrigation and its effects on drinking water, human health, and such environmental assets as wetlands. Second, to understand all these multiple uses of water as a whole, we have increased the scale of our research from the microscale of individual irrigation projects, to the mesoscale of the irrigation sector as a whole, and to the macroscale of water supplies, demands, and competition for scarce water resources at the levels of entire river basins, nations, and global regions.

To more accurately portray these changes in IIMI's focus and mission, the Board of Governors has approved a

change in our name from the International Irrigation Management Institute to the *International Water Management Institute (IWMI)*. Since IIMI is registered in Sri Lanka, this change must also be approved by the parliament of Sri Lanka. We hope that approval will be obtained by the end of 1998.¹

In several major areas of the world, water scarcity is already constraining food production and economic growth and it is having highly detrimental effects on human health, the quality of life, and conservation of environmental assets. All of these adverse effects descend on poor people disproportionately because they lack the means for competing for scarce water resources and of escape from the adverse effects scarcity imposes on their lives.

Water scarcity is going to substantially worsen in the next century. IIMI projects that fully one-third of the

¹Also, in the interests of easy speech, we drop the "W" in the pronunciation of our acronym and simply say "IMI."

populations of developing countries will suffer from severe water scarcity by 2025. Nearly all of these people live in the West Asia and North Africa region, in the arid zones of India and China, and in sub-Saharan Africa. Perhaps the single greatest threat to water security in many of these regions is the depletion and pollution of groundwater supplies. This is a major threat to food security—India already obtains one-half of its irrigation water from groundwater—and to human health and welfare.

So what is IIMI doing about it? IIMI is both a research and a development institute. We strongly believe that before you act you must think—and you must think carefully, rigorously, and with empirical tests of hypotheses. Nowhere is this more important than in the enormously complex field of water resources management in developing countries. Here the complex technical aspects of water management must be combined with the even more complex institutional aspects. That, in a nutshell, is what we are doing.

We believe that we are making rapid progress on both fronts. IIMI has historically been strongest in the institutional aspects of water

management. It is internationally known, for example, for its research and promotion of devolution of irrigation management to water users associations. But, it also has become increasingly clear that the state of the technical science of water, upon which water management ultimately rests, is not adequate for proper policy and management analyses and, indeed, in many cases has produced counterproductive results. Thus, IIMI has been investing heavily in the technical sciences while at the same time maintaining its strength in the institutional aspects of water. We believe that now we have made sufficient advances in both of these crucial aspects of water policy and management and that we are now in a position to emphasize more the development side of IIMI through assisting water agencies and farmers to more effectively and efficiently manage their scarce resources. If properly accomplished, these action programs will contribute substantially to our research and provide a means of testing hypotheses in action: they are *action research*.

The selected chapters in this report reflect all these new directions in IIMI. 1997 has been an exceptionally exciting and productive year in IIMI.

David Seckler
Director General

Zafar Altaf
Chairperson
Board of Governors

Basin Water Resources Management in Turkey

Although the water management practices for irrigation schemes can be evaluated and improved using modeling techniques, looking at irrigation schemes in isolation from other water uses within a river basin may not be effective. Changes in irrigation schemes—management, facilities, crop patterns, fertilizer, and pesticide use—may affect other users in the basin. And changes in other water uses—industrial, power production, and urban water supplies—can affect the quality and quantity of water for irrigated agriculture. As demand and competition for water increase, these links become more and more important, and real increases in the productivity of water are essential if the requirements of all users are to be met. Consequently, the models applied in this project are designed to simulate irrigation schemes within the overall water resources of the Gediz basin.

The Gediz basin

The Gediz river, around 275 km long, drains an area of 17,220 km² and flows from east to west into the Aegean Sea just north of Izmir, Western Turkey (see figure 1). The river network is controlled by four main reservoirs and four regulators are used for irrigation diversions. River flows from the heavy winter precipitation are stored in the main reservoir Demirköprü for release over the summer irrigation period. Precipitation in the basin ranges from over 1,000 mm per year in the mountains to 500 mm per year near the Aegean coast.

Crop production within the basin includes cotton, cereals, grapes, vegetables and fruits, olives, tobacco, and melons. The total irrigated area in the basin is about 150,000 hectares.

Figure 1. Map of Turkey showing the location of the Gediz basin.

Other activities in the basin include textile factories, weaving, salt production, and leather works. Urban areas within the basin are expanding and groundwater is extracted to supply water to the city of Izmir, located just outside the basin to the south.

The hydrological models

Three different scales of hydrological models are used in the study (see figure 2). At the smallest scale, the field, the vertical water balance Soil-Water-Atmosphere-Plant (SWAP) model is used to show the relationships between water quantity and quality, and crop yields. At the intermediate or irrigation scheme level, the SWAP integrated model is used

to represent types of crop, types of soil, and types of irrigation. This model provides information on the effects of management changes in water distribution and allocation on the productivity of irrigation schemes. At the largest scale, the SLURP hydrological model is being applied to the whole basin. This model divides the water basin into many subbasins known as aggregated simulation areas (ASA) illustrated in figure 3. Within each ASA, the model simulates each different land use separately. The detailed information derived from each land use within each ASA is integrated and routed down through the basin by the SLURP model including the effects of regulation and diversions. This provides an evaluation of each irrigation scheme against the

Figure 2. Three different scales considered in the modeling activities.

prevailing basin-wide water management practices and water availability. Modifications in irrigation practice and climate variability are also taken into account in the model, and the hydrologic impacts of climate change can be evaluated.

Transferring data and information between the three modeling scales and integrating the outputs of all three models allow us to see the performance

of individual crops within irrigation schemes in the context of the overall water resources of the basin.

Putting it all together

A digital elevation model from a United States Geological Survey (USGS) data set—available on the internet—was used to define the basin boundaries and river networks, to subdivide the basin, and to

Figure 3. Aggregated simulation areas (ASA) of the Gediz basin.

calculate the distances traveled by water to the nearest stream and down the stream network to the respective ASA outlets. The topographic map and river network shown in figure 4 are products of the application of the TOPAZ topographic analysis program to the USGS data set.

Using satellite remote sensing techniques, a land cover classification for the Gediz basin was established. This

was derived by classifying 1 km resolution U.S. National Oceanic and Atmospheric Administration (NOAA) images of Advanced Very High Resolution Radiometer (AVHRR) satellite data available on the internet (see figure 5). This classification has been verified by field studies.

To obtain measurements of irrigated and nonirrigated crop yields, leaf area index (LAI) data were derived from

Figure 4. Topographic map and river network of the Gediz basin.

Figure 5. Land cover map of the Gediz basin.

Normalised Difference Vegetation Indices (NDVI) obtained from an analysis of NOAA-AVHRR satellite images. In the Mediterranean climate of the Gediz, many of the natural vegetation types (e.g., coniferous forest and *maki*, a Mediterranean scrubland) show little variation in LAI through the year. This emphasizes the large variations in the introduced irrigated and nonirrigated crop classifications. The NDVI and leaf area index for the nonirrigated crops peak in April at the end of the rainy winter season. For the irrigated crops, the peaks are reached during the July and August irrigation season.

Early results

This study is still in its early stages but some early results are already available. At the smallest or field scale, the performance of the SWAP model was

verified by comparing measured and simulated soil moisture profiles. As can be observed from figure 6 a good agreement between measured and simulated moisture profiles exists, indicating that the choice of model and data is appropriate for the conditions in the Gediz basin.

Moving up from the field scale to the irrigation scheme scale, the processes of interaction of water with soils and plants are analyzed in detail. In 1989, a major drought occurred in the upstream part of the Gediz basin, resulting in a large decrease of inflow to the main reservoir and a consequent reduction in the water available for irrigation. For two successive years, one before and one during the drought, integrated SWAP simulations were carried out and soil moisture contents were obtained. Figure 7 displays one of the main advantages of using models in comparison with field mea-

Figure 6. Measured and simulated moisture profiles for a cotton field on a loamy soil in the Gediz basin.

Figure 7. Soil moisture contents for the cotton area in the alluvial soils for one of the main irrigation schemes. Two years are shown, one before the drought (1988) and one during the drought (1989). The red areas indicate deficiency in water for cotton growth.

surements—the high resolution in terms of space and time that can be obtained.

Using the SWAP model all the components of the water balance for the cotton area in the alluvial soils for one of the main irrigation schemes were simulated (figure 8). Knowledge of the entire water balance is essential to understand where improvements in water usage can be made. It can also be seen (figure 8, bottom) that almost 200 mm of water evaporate directly from the soil each year. It should be noted that, while the evaporation from soil can be considered as a real loss to the water users' community, the water flowing into the groundwater may be used downstream by other users. This water is subject to any changes in quality that occurs during the process. Clearly, this indicates the need of a basin scale approach to irrigation studies.

Using the basin-scale SLURP model, two different irrigation methods were simulated for an irrigation scheme in a particular ASA (Gedabala, see figure 3). For each method the irrigation started on 15th of July. Figure 9 shows the simulated evapotranspiration of the irrigated crop for the different methods. It also shows that with the sprinkler method, the actual evapotranspiration (ET actual) is at potential rate (ET potential) for longer than for furrow irrigation (figure 9). However, it is probable that not all the ET from the sprinkler irrigation is transpiration and that some will be evaporation from canopy interception. The furrow method (figure 9, bottom) shows actual evapotranspiration reaching potential from the first day of irrigation, but due to runoff and percolation, the water available to the plant was inadequate 22 days after the irrigation event. The same

Figure 8. Annual water balances for the cotton area in the alluvial soils for one of the main irrigation schemes.

Figure 9. Actual and potential evapotranspiration of different irrigation methods in the Gedabala ASA.

quantity of water met full ET needs for 25 days in the case of sprinkler irrigation.

The basin-scale SLURP model may also be used to simulate other water uses within the basin and the interactions between them. For example, the largest

reservoir in the basin, Demikköprü, has a comparatively large hydroelectric power-generating station but this is used only during the irrigation season. The SLURP model can be used to simulate inflows to the reservoir and to investigate alternative generating strategies and their effect on downstream irrigation schemes.

Where to next?

The joint Government of Turkey and IIMI Gediz basin study has, to date, successfully developed new tools that can evaluate irrigation at a variety of scales—at the field level, at the irrigation scheme level, and at the basin scale. Each model uses common data sets and the information obtained can safely be transferred from one scale to another.

At the crop scale, the SWAP model can relate the quantity, quality, and timing of irrigation water to crop production. At the scale of the individual irrigation scheme, an integrated SWAP model can take account of factors such as crop choice, amount and timing of irrigation supply, source of irrigation water (surface water or groundwater), and alternative delivery mechanisms. Further, the model is able to incorporate the information on performance derived from the crop-scale model with the water supply information provided by the basin-scale SLURP model.

The basin-scale hydrological model is able to bring together the basic data on

the irrigation schemes, set it in a broader basin context, and include information on the climate and river flows. The basin-scale model can then be used to investigate the hydrological and hydraulic relationships between different water uses within the basin. Apart from the climatic data and data specific to regulation rules and irrigation, all the information used to drive the hydrological model was freely obtained from public-domain databases on the internet.

So, where to next? Plans are now in hand to use these models to investigate the effects of alternative crops, alternative management practices, and alternative water supply scenarios. The use of these models will provide a fuller investigation of the true performance of irrigation schemes under various water management and water availability options. New measures will be tested and applied to increase the productivity of water through better management of irrigation and water basin systems.

Use and Productivity of the Nile Water in Egypt

There is increasing competition for water between agriculture, industry, and domestic uses. Because water is often in limited supply, there is a requirement to use the water more productively. As there is a high interdependency among users, considerable effort is being placed on improving the integrated management of water resources.

As a large consumer of water, developments in irrigation have profound impacts on basin-wide water use and availability. Higher demand from the other sectors means reduced supplies to irrigation so irrigated agriculture needs to produce more with less water. Yet, planning and execution of interventions in irrigation often take place without consideration of other uses. Similarly, other actions related to the water resources do not sufficiently consider the effects on irrigation.

Although there is a clear need to think of irrigation within the broader context of basin-wide water resources, there are inadequate methods to describe how irrigation water is being used in relation to other uses. Irrigation efficiency is the most commonly used term to describe how well water is being used. But, increases in irrigation efficiency do not always coincide with reduced competition for water, nor do they necessarily coincide with increases in overall productivity of water in a basin.

This report describes a water accounting framework that is designed to measure the use and productivity of water resources in a water basin. The method was developed around an irrigation perspective to better understand the impacts of irrigation interventions at the water-basin scale,

Water accounting helps with efforts to increase the productivity of water to ensure food security for all.

and the impacts of other water-related activities on irrigated agriculture. The accounting procedures are designed to be universally applicable for evaluating water management among all sectors.

Levels of analysis

Agricultural researchers often focus on a field or a plot level dealing with crop varieties and farm management practices. Irrigation specialists focus on a set of fields tied together by a common resource—water. Water resources specialists are concerned with other uses of water beyond agriculture, including municipal, industrial, and environmental uses.

To understand the impacts of actions at any level, an analysis of the interactions among these levels is

essential. For example, a perceived improvement in water use at the farm level may improve overall productivity of water in a basin, or it may reduce productivity of downstream users. Similarly, basin-wide studies may reveal general concepts about how water can be saved, or productivity of water increased, but field-level information is required on how to achieve the savings or increase the water productivity.

The methodology—developed so that it could be used for irrigation, municipal, industrial, environmental, or other purposes—defines three different levels of water use. It develops water accounting procedures at each level:

- macro level—*basin or subbasin level*, covering all or part of a water basin, including several uses of water

- meso level—*water services level*, such as irrigation or municipal water services
- micro level—*use level*, such as an agricultural field, a household, or an environmental use

Water balance approach

The water accounting methodology is based on a *water balance* approach. Water balances consider inflows and outflows from basins, subbasins, and service and use levels such as irrigation systems or fields (figure 10).

The initial step in performing a water balance is to identify a *domain of interest* by specifying spatial and temporal boundaries of the domain. For example, a domain could be an irrigation

system bounded by its headworks and command area, and bounded in time for a particular growing season. Water accounting considers various components of the water balance and classifies them according to uses, and the productivity of these uses.

Conceptually, the water balance approach is straightforward. Often though, many of the components of the water balance are difficult to estimate or are not available. For example, groundwater inflows and outflows to and from an area of interest are difficult to measure. Estimates of actual crop consumptive use at a regional scale are questionable. And often, drainage outflows are not measured as more emphasis is placed on knowledge of inflows. In spite of these limitations, experience has shown that even a gross estimate of water balances for use in

Figure 10. Water accounting integrates water balance information with uses of water at the river basin level.

water accounting can be useful for water and irrigation managers, farmers, and researchers.

Water accounting definitions and performance indicators

The art of water accounting is to classify water balance components into water use categories that reflect the consequences of human interventions in the hydrological cycle. Water accounting integrates water balance information (see box) with uses of water at the river basin level.

The performance indicators for water accounting are presented in the form of fractions and in terms of productivity of water. The productivity of water can also be defined in terms of gross inflow, net inflow, available water, or depleted water. In a river basin it makes sense to

track gross productivity of water over time to see how well the overall water resources are being used. For an irrigated service area, these are the external indicators of system performance that relate the output of irrigated agriculture to its main input, water.

Accounting for Nile water use

The water accounting method was applied to Egypt's Nile river system for the agricultural year 1993–1994. The inflows and outflows were measured and, assuming there was no change in storage, the evaporation and transpiration values were calculated. Crop evapotranspiration was subsequently calculated after estimating other sources of non-crop evapotranspiration. The values for the balance are summarized in figure 11.

Figure 11. Water accounting for Egypt's Nile river below the High Aswan dam for the agricultural year 1993–1994.

Water Balance Information

- *Gross inflow* is the total amount of water flowing into the domain from precipitation, and surface and subsurface sources.
- *Net inflow* is the gross inflow plus any changes in storage.
- *Water depletion* is a use or removal of water from a water basin that renders it unavailable for further use. Water depletion is a key concept for water accounting, as interest focused mostly on the productivity and the derived benefits per unit of water depleted. It is extremely important to distinguish water depletion from water diverted to a service or use as not all water diverted to a use is depleted. Water is depleted by four generic processes:
 - *Evaporation*: water is vaporized from surfaces or transpired by plants.
 - *Flows to sinks*: water flows into a sea, saline groundwater, or other location where it is not readily or economically recovered for reuse.
 - *Pollution*: water quality gets degraded to an extent that it is unfit for certain uses.
 - *Incorporation into a product*: by a process such as incorporation of irrigation water into plant tissues.
- *Process consumption* is that amount of water diverted and depleted to produce an intended product.
- *Non-process depletion* occurs when diverted water is depleted, but not by the process for which it was intended.
- *Committed water* is that part of outflow that is committed to other uses.
- *Uncommitted outflow* is water that is not depleted, nor committed and is therefore, available for a use but flows out of the basin due to lack of storage or operational measures. With better management, or additional storage, this uncommitted outflow can be transferred to a process use such as irrigation or urban uses. Uncommitted outflow can be classified as *utilizable* or *non-utilizable*. Outflow is utilizable if by improved management of existing facilities, the water could be consumptively used. Non-utilizable uncommitted outflow exists when there are insufficient facilities to capture the outflow.
- A *closed basin* is one where there are no utilizable outflows in the dry season. An *open basin* is one where uncommitted utilizable outflows exist.
- In a *fully committed basin*, there are no uncommitted outflows. All inflowing water is committed to various uses. In this case, major options for future development are reallocation among uses, or decreasing non-process, non-beneficial depletion of water, or importing water into the basin.
- *Available water* is the net inflow less the amount of water set aside for committed uses and less unutilizable uncommitted outflow. It represents the amount of water available for use at the basin, service, or use levels. Available water includes process and non-process depletion, plus uncommitted water.

Water accounting and indicators

The water accounting components are summarized in table 1. Process depletion includes evapotranspiration, municipal and industrial uses, and navigation. Non-process depletion includes evaporation from free surfaces, fallow land, vegetation, and drainage to the sea. The total available water is calculated after subtracting the water committed for environmental uses from the gross inflow. The results showed that in the Egypt Nile river all the available water is depleted and there are no uncommitted utilizable outflows.

Accounting indicators were calculated to characterize the use of Nile water. They are based on ratios of various depleted amounts to gross, net, total depleted, and available water. They are presented as fractions and are summarized in table 2.

The agricultural productivity of Nile water

The productivity of agriculture can be measured in several ways. With the multiple food and nonfood crops existing in Egypt's Nile subbasin it is intuitive to use a monetary value for production. Both gross and net value of production are considered. An ideal expression of basin water productivity should consider the sum of net benefits obtained from agricultural, fisheries, navigational, environmental, industrial, municipal, and other uses. Valuing the productivity of all the uses can be quite difficult, especially in environmental and municipal sectors, so this was not undertaken in this study.

Instead, the research focused on the productivity of the irrigated agriculture sector. In 1993–1994, the total gross value of production of the irrigated agriculture sector was estimated at 24.8 billion Egyptian pounds—equivalent to US\$7.5 billion at 1993 prices.

The productivity of water was calculated as the gross value of production per gross inflow of water. An essential measurement in this calculation was to consider the value of production related to crop evapotranspiration—the process depletion for agriculture. It was found that the value of productivity of water consumed by evapotranspiration—US\$0.20 per m³—compared quite favorably with other irrigated systems.

Trends in water use and productivity

Past and future water supply and utilization can be understood by tracking certain key variables. Figure 12 illustrates the major inflow to the domain—releases from the High Aswan Dam (HAD)—and the most significant outflows from the domain—through crop evapotranspiration, drainage outflow to the sea, and outflows from the Nile river to the sea.

There has been a clear reduction of Nile outflow to the sea in recent years (figure 12). From 1974 to 1980 the average annual Nile flow to the sea was 6.2 km³, from 1981 to 1990 it was 3.9 km³, while from 1991 to 1996 it was reduced to 1.7 km³. For the 1995–1996 irrigation season, the Nile outflow to the sea was reduced to 0.26 km³. To save water for use in agriculture and other

Table 1. Water accounting components of Egypt's Nile river.

	Total km ³	Component km ³
Inflow		
Gross inflow	56.2	
Surface diversions from the High Aswan Dam	...	55.2
Precipitation	...	1.0
Subsurface sources from outside the subbasin	...	0.0
Surface drainage sources from outside the subbasin	...	0.0
Storage change	0.0	
Surface	...	0.0
Subsurface	...	0.0
Net inflow	56.2	
Outflow		
Total outflow	14.2	
Surface outflow from rivers	...	1.2
Surface outflow from drains	...	12.5
Subsurface outflow	...	0.0
Flow to Fayoum depression	...	0.5
Committed water	8.0	
Environment maintenance (assumed)	...	8.0
Available water		
Total (gross inflow less committed water)	48.2	
Depletive use		
Process depletion	40.3	
Evapotranspiration	...	36.8
Municipal and industrial uses	...	2.3
Navigation	...	1.2
Non-process depletion	8.0	
Outflows in excess of environmental requirements	...	5.0
Other evaporation (phreatophytes, free water surface)	...	2.9
Total depletion	48.2	

Table 2. Water accounting indicators.

Accounting Indicators	Value
Depleted fraction — of gross inflow	...
of available water	...
Process fraction - all uses — of gross inflow	...
of available water	...
Process fraction for irrigated agriculture	
Available for agriculture in km ³	...
Irrigated agricultural process fraction	...

sectors, managers have been devising ways to close the route of water to the sea. The data show, however, that future potential for further water savings of the Nile river water is very limited.

Data for drainage outflow to the northern lakes and the sea are available from 1984 and are maintained by the Drainage Research Institute, Egypt. As illustrated in figure 12, changes in drainage outflow to the sea have been less significant than for the Nile outflow. Unlike the situation with the Nile outflow, it has been difficult to reduce the drainage outflow to the sea. One possible factor for the lack of reduction in drainage outflow, in spite of conservation efforts, is that rice irrigation in the northern delta area contributes heavily to the drainage outflows.

During the same period, crop evapotranspiration has shown a steady increase. Given the ongoing expansion of agriculture, plus the increase in yields

on existing land, this trend is expected to remain on course for the next few years.

Over time, the production value of Egyptian agriculture has shown an upward trend. The increase in gross value of crop production is a result of several factors including increased productivity, growing of higher-valued crops, and the expansion of irrigated land.

Agricultural productivity per cubic meter of gross inflow provides a means of tracking performance of Egyptian irrigated agriculture (figure 13). From the 1970s to the 1990s, this value has nearly doubled. This trend is expected to increase in the near future with the expansion of irrigated land, economic liberalization, the shift to higher-valued crops, and increasing productivity. If old lands are taken out of production through salinization or lack of water in order to serve new facilities, it is possible that this trend

Figure 12. Water supply and use of the Nile river below the High Aswan Dam (HAD).

Figure 13. Trend of gross value of production per cubic meter of water for agricultural crops. Values are in constant 1993 US dollars.

could reverse. The gross value of production per unit of evapotranspiration (ET) for the period of the water balance analysis ranges between US\$0.20 and US\$0.25 per m^3 .

Improving the productivity of water

The picture of water use and productivity emerging from the analysis shows agriculture as the dominant user, with depletive use by municipalities and industries—a small but growing factor. A very high percentage of inflowing Nile water is being depleted and most of this depleted water is being put to productive use. The productivity of water in agriculture is quite good, with the productivity of gross inflow at US\$0.13 per cubic meter and increasing. But, as demands in the agricultural, environmental, urban, and industrial sectors increase, opportunities for water savings are becoming more difficult to find.

One opportunity to increase the productivity of Nile water would be to capture more of the drainage outflow and convert it into a productive use. However, initial estimates based on downstream environmental outflow requirements show that only 4 to 5 km^3 can be captured with aggressive conservation efforts. Other efforts that may be required include storage and further reuse of water.

Outflow into the northern lakes and the sea is a significant, but not well-understood factor in determining how much water still remains to be captured and placed for productive use. Much of the existing outflow is required to flush salts and other pollutants out of the system, and to maintain an economically viable fisheries industry.

The Nile river below the High Aswan Dam is an example of a “closing” water basin. There is little opportunity for

water resources development or water savings. To obtain additional water for a depletive use, water reallocation within and between sectors is becoming more important. It is likely that this water will come from agriculture and be reallocated to municipal, industrial, and environmental uses.

The response to this “closing basin” situation has been in many ways, remarkable. Water savings have been achieved, particularly through increased reuse. Water productivity has shown a gradual rise per unit of inflow, and remains relatively high per unit of evapotranspiration.

In light of increased competition between sectors, the challenge is to sustain the water productivity increase to match the needs of the rising population. Even within the agriculture sector, there is a desire both to expand irrigated agriculture to new lands and to increase productivity of existing lands. The most important means of increasing water productivity will be to find ways to increase the returns per unit of crop evapotranspiration. This is possible through switching to higher-value crops,

or using crops or agronomic practices that produce more but consume less. Identifying the necessary technologies, management, strategies, and policies to obtain higher productivity is an important area of strategic research for Egypt.

The role of water accounting

The water accounting procedure applied to Egypt's Nile river system allowed evaluation of the present status of water use and productivity trends over time, and provided an indication of where gains can be made. While the procedure sufficiently described the Nile system, it has yet to be demonstrated in situations with more rainfall and with more variability in climate.

Worldwide, many water basins are facing perceived water shortages due to increasing demands on water from all sectors. It is vital that key information is presented in a way that can benefit policy makers. Choices, tradeoffs, and evaluation of use must be described as clearly as possible. This is the role for water accounting.

Estimating the Productivity of Land and Water at the Bhakra Irrigation System in India

Last year, we reported on studies designed to answer the question of whether advanced technologies—satellite remote sensing, geographical information systems, and hydrological modeling—could be successfully used to assess irrigation performance. Having shown the utility of these techniques in performance assessment, these studies have been extended to appraise their use in estimating the productivity of land and water.

Given that water is an increasingly scarce resource and a binding constraint to agricultural production in many areas, it is important to better understand how to use it in a more productive, equitable, and sustainable manner. Traditionally,

output measures of irrigated agriculture have focused on the productivity of land. In many irrigated areas, water is scarce relative to land. Where this is true, ways of increasing productivity must focus on getting more production per unit of water.

The “productivity per unit of crop evapotranspiration” is a basic and important measure of performance of irrigated agriculture, especially in water-scarce conditions. Managing water in ways that allow for more productive use at farm, irrigation system, and river basin levels is an increasingly important task. The productivity of water embraces two basic measures: crop yield and actual evapotranspiration. Both are expressed as

a unit of land and are quite difficult to measure.

Measuring the productivity of land and water resources, and finding explanations for high or low productivity constitute the focus of an increasing number of irrigation performance studies. Studies based on conventional field data collection are often hampered by lack of detail on the distribution of crop yield and actual evapotranspiration (if actual evapotranspiration can be measured at all). By

contrast, analyses by satellite remote sensing provide objective, repetitive, and detailed information over large areas.

This current study reports on the effectiveness of remote sensing in providing information on the productivity of land and water resources use in irrigated agriculture. The work—undertaken in the Bhakra irrigation system, Northwest India—consisted of calculating the actual wheat yield and actual crop evapotranspiration during the *rabi* (winter) irrigation season of 1995–1996.

The Bhakra irrigation system

The Bhakra irrigation system serves more than 1.2 million hectares in the state of Haryana, India. The system yields about 40 percent of Haryana's wheat production and around 6 percent of the national wheat production. The Bhakra system comprises 5 administrative water service circles: Ambala, Khaital, Hisar-1, Hisar-2, and Sirsa (figure 14).

Canal systems in Haryana were designed with the objective of distributing a limited supply of water over a large area to serve the greatest number of farmers possible. The system was designed and is operated using the *warabandi* principle—the right to irrigate in proportion to landholdings. The canal system is designed for an annual irrigation intensity of 62 percent of the cultivable command area. The cultivated land receives canal water during the *rabi* season, often in conjunction with groundwater to supplement the under-irrigation from canal water. The main *rabi* crops are wheat, oilseed, and gram.

Increasing the productivity of water contributes towards achieving sustainable livelihoods for poor people.

Figure 14. The Bhakra irrigation system in Haryana, India.

Satellite images

Important measurements required in the study were taken by satellite remote sensing. The cropping patterns and crop yields were analyzed with IRS-LISS (Indian Remote Sensing Satellite-Linear Imaging Self Scanning) measurements. The evapotranspiration computations were performed using Landsat-Thematic Mapper (TM) and NOAA-AVHRR (National Oceanic Atmospheric Administration-Advanced Very High Resolution Radiometer) measurements. The IRS satellite-related data were purchased at a unit cost of about US\$0.03 per hectare and the analysis

of irrigated areas, crop identification, and wheat yield prediction took 8 months to complete. Processing monthly NOAA data was completed in 14 days and a unit cost of processing was US\$0.01 per hectare.

Estimates of the productivity of land

Information on vegetation density is of paramount importance for estimating biomass accumulation and grain yield. Measurements of vegetation density were estimated by calculation of the Normalized Difference Vegetation Index

(NDVI). The NDVI at the heading stage of wheat was determined from the analysis of four different IRS images acquired during the 1995–1996 rabi season. Yield data obtained from crop-cutting experiments were taken from 151 individual fields scattered throughout the entire Bhakra canal command area. This was done to derive a statistical relationship between NDVI and wheat yield. It was found that the NDVI of a single satellite image during the heading stage of the crop was sufficiently accurate to predict the wheat yield.

To estimate wheat yield, crops were identified from the satellite images using a classification procedure that resulted in the identification of wheat with a 95 percent accuracy. Subsequently, the statistical relationship between wheat yield and NDVI was applied for each image pixel that had been labeled as wheat for the entire 1.2 million hectare Bhakra canal command area. These estimates of wheat yield could be aggregated over any desired area such as a distributary/minor command, a branch canal division, or a water service circle.

The results of the analyses revealed that the maximum wheat yield occurred in the Kaithal circle, an area that has access to fresh groundwater. The minimum wheat yield occurred in the Hisar-1 and Sirsa circles, both of which are underlain by marginal and saline groundwater. The average wheat yield over the whole Bhakra canal command area was estimated to be 4.09 t/ha.

The wheat yields from the distributaries and minor distribution canals were computed and compared

with mean wheat yield at the divisional level. Those distributaries and minors displaying less than 90 percent of divisional mean wheat yield were identified as possible problem areas. It was shown that 53 of the 364 distributaries/minors in the command were under-performing in the 1995–1996 rabi season. This information was provided to irrigation managers so they could identify and diagnose the underlying causes for under-performance.

Crop water consumption

Estimation of evapotranspiration from satellite measurements has intrigued scientists for the last 20 years. To date, scientific progress has been obtained at microscale on a limited number of fields being heavily equipped with electronic devices to measure complex micro-meteorological parameters as support to satellite data. To overcome this dependency on direct meteorological measurements and the limited area they serve, a new remotely sensed data-based Surface Energy Balance Algorithm for Land (SEBAL) methodology was applied. This model, developed and tested over the last 5 years on large-scale irrigation systems in China, Egypt, Spain, Argentina, and India, was used to develop a regional evapotranspiration map. The results show spatial variations of evapotranspiration (figure 15) that indicate the crop consumptive water use is nonuniform. This result agreed nicely with the findings of the irregular wheat yield variations. Waterlogged and barren land could be recognized from the respective high (2.0 mm/day) and low (0.1 mm/day) evapotranspiration rates.

Figure 15. Spatial patterns of actual evapotranspiration based on Landsat Thematic Mapper and SEBAL model in December 1995.

SEBAL provides a picture of evapotranspiration over 24 hours. To obtain the productivity of water consumed, the amount of evapotranspiration for the entire growing season is required. This was obtained by integrating measurements of evapotranspiration across the entire growing season—from 21 November, 1995 to 15 April 1996—using NOAA-AVHRR data. A total of six NOAA cloud-free images were used (one image for each month from November 1995 to April 1996) to compute the actual evapotranspiration rate variations in time. The monthly evapotranspiration was adjusted for the cloudiness on each day of the month and for the growing period of the crop to obtain the total actual evapotranspiration for the whole season.

The results of actual crop consumptive use were estimated to be 374 mm for Hisar, 450 mm for Ambala,

and a variation between 180 and 410 mm for Sirsa. These results coincided well with the values computed from physically based hydrological models.

Productivity of water consumed by crops

An innovative aspect of this study was the calculation of the productivity of water consumed by crops—crop per drop—for an area of 1.2 million hectares. By overlaying the AVHRR with the IRS images, the area under wheat crop was related to the evapotranspiration. Figure 16 shows this relationship for 269 distributaries and minors in Haryana. The trend is linear indicating that the productivity of water in this large irrigated area is not that variable.

Canal and on-farm water management procedures may affect the productivity of land by enhancing actual

Figure 16. Relationship between grain yield of winter wheat obtained with 30 m IRS data and the accumulated actual evapotranspiration across the growing season obtained with 1.1 km NOAA data at distributary/minor level.

evapotranspiration and influencing the selection of crop varieties. The spatial variations in the productivity of water are however, fairly constant. Figure 17 shows that the range in productivity of water was limited to 0.8–1.3 kg/m³ and that the productivity of most areas ranged from 0.9 to 1.2 kg/m³.

The distributaries with lower and higher water productivity were located in all irrigation circles and no systematic relationship was detected between water productivity and climate, salinity, head-tail, or soil type. Reasons for finding lower water productivity in certain areas could be the unreliability and inadequacy of canal water deliveries, conditions of the canal lining, depth to the water table, and soil salinity. This however, requires further in-depth analyses. Cropping intensity, application depth, tube well use, and degree of contiguity in cultivation and irrigation practices may also influence the productivity of water in these areas.

The current status

This study has demonstrated that satellite remote sensing is able to provide information on the productivity of land and water for a season on the 1.2 million hectare Bhakra irrigation system.

Wheat yield estimates were made on a 30 m pixel basis—0.09 hectare—for the entire area yielding a gross value of productivity for land resources at a unit cost of only US\$0.03 per hectare. The study also demonstrated that crop consumptive use of water on a seasonal basis can be estimated on a 1,100 pixel basis (121 hectares) using low cost NOAA images and standard climatic data from a meteorological station at a unit cost of US\$0.01 per hectare. Combining the measures of yields and crop consumptive use gave the productivity per unit of crop evapotranspiration for the whole command area. The standard gross returns to water (US\$/m³) can also be computed based on international pricing systems (US\$/kg).

Figure 17. Spatial patterns of the productivity of water for the different distributaries/minors in the Bhakra irrigation system.

Using the productivity maps, water managers can inform water users on the performance of their land and water resources, and provide important information to identify problem areas for investigation and rehabilitation.

While the approach taken to make an estimate of evapotranspiration over a season is novel, it needs to be validated more thoroughly. More research is required to find better ways of incorporating the results from a limited number of satellite images to get seasonal values of evapotranspiration.

Nevertheless, the study shows that objective information on evapotranspiration and production can be

obtained from satellite remote sensing. This provides the means to understand how water resources are presently being used, and identifying areas where the use of the water resources can be improved. The information can also be used in water balance and water accounting studies to understand how much water is being used and which crop or agro-ecological zone is depleting the water resources. Furthermore, returns to water from different sectors can be more accurately estimated and returns to water from extensive agricultural areas accurately computed. With decreasing costs, the use of satellite remote sensing will become an increasingly important tool in integrated water resources management.

Water Management in the Twenty-First Century

The total supply of water in most river basins is essentially fixed. As water is reallocated away from agriculture to other uses, it creates the most profound challenge facing agriculture today—how to produce more food with less water. The primary challenge in the water sectors of developing countries is how to cope with the rising competition for water between multiple kinds of users in ways that are equitable, efficient, and sustainable. For developing countries with limited financial resources and weak civic institutions, this challenge is particularly daunting because poor and disadvantaged people are likely to suffer disproportionately from scarce and polluted water supplies. To deal with this situation, four important changes in the water sectors of developing countries are necessary:

- replacement of administrative organizations with service delivery organizations

- conversion of irrigation systems into multiuse water service systems
- transcending the infrastructure dependency-deterioration trap
- implementing integrated water basin management

The consequences of not coping effectively with these challenges will have a significant impact on all aspects of water use. But coping with them effectively will require fundamental changes in the nature of the water sector institutions in developing countries.

From administrative organizations to service delivery organizations

It is well-known that a multitude of technical solutions to problems of

Today's challenge is to grow more food with less water.

irrigation management have been recommended and tested in pilot projects only to be ignored, abandoned, or even sabotaged at the stage of adoption or implementation. For example, basic technical solutions to the problems of waterlogging and salinization in irrigated areas have been known and recommended by technical experts for several years. But salinization continues to advance in many countries, especially in Pakistan, India, Iran, Iraq, and northern China. It is estimated that of the world's 270 million hectares of irrigated land, 20 to 30 million hectares are severely affected by salinity while another 60 to 80 million hectares are affected to a lesser extent. So, waterlogging and salinity continue to reduce the productivity of irrigated farm lands. The processes continue in spite of

the recommended practices for sound water delivery and application, investment in needed drainage infrastructure, and maintenance of drains.

The maldistribution of water within irrigation systems, especially between the head and tail ends, is another well-known example. Maldistribution of water is endemic in large-scale canal irrigation systems, especially in South Asia, where hundreds of thousands of hectares of irrigable land fail to receive surface irrigation water because excessive amounts of water are taken by the head enders or by politically powerful farmers. Also, rent-seeking, low-paid civil servants are often drawn into systematic patterns of misallocation. Even where there is little corruption, public agencies lack the incentive systems for personnel in field

operations to ensure that performance standards are met.

It is this lack of performance-orientation in public bureaucracies and farmer organizations that has seriously undermined management performance. Generally, neither the budget nor the personnel of a public bureaucracy are dependent on achievement of performance targets. And sanctions are rarely applied against farmers who violate official water distribution rules, either because such farmers are powerful, or because farmer groups or village governments are too weak to impose sanctions. Consequently, two challenges are seen where performance-oriented management will be particularly important in the future:

- increasing the productivity of water
- halting or reversing environmental degradation

The emphasis in agricultural development so far has been on improving the productivity per unit of land. But, as the main constraining resource in the future will be water, the agricultural productivity per unit of water will become the key concern. This means that irrigation organizations will have to become accountable for how much water they deliver, and even how productively their customers use it. They will also have to become accountable for halting or reversing environmental degradation. As a consequence, new kinds of organizations—water service entities that promote productivity per unit of water subject to requirements for environmental conservation—will emerge.

Conversion of irrigation systems into multiuse water service systems

As rural populations become denser, demand for water for domestic and other uses as well as for irrigation is rising, leading to competition within irrigation systems as well as between irrigation and other sectors. This is compounded by the rising expectations that water will be managed in a way that contributes to maintaining the overall landscape and natural environment. Irrigation systems have now become “water supply” systems and this has profound implications for the future management of these systems, and for the well-being of local people.

In its ongoing research on irrigation systems, IIMI is trying to document and economically value the multiple uses of water. In addition to agriculture, these include the full range of domestic uses such as drinking, cooking, bathing, laundering, and watering livestock; fishing; small industrial uses such as brick-making; and environmental maintenance such as sustaining wetlands. Except for the occasional “domestic issues” of water between growing seasons, none of these uses are officially recognized by irrigation management agencies. There is a growing gap between the assumptions underlying the design and operation of irrigation systems, and the pervasive reality of the multiple uses of this irrigation water.

Transfer of irrigation management from governments to users often involves the transfer of irrigation systems to irrigators alone. The local institutions are legislated and organized to manage water

only for the primary purpose of irrigation, not for the multiple purposes for which the water is actually being used. The “users” represented are often limited to cultivators, and usually only male cultivators.

In the future, local water management institutions will have to be able to meet the diverse demands of their customers, and provide water services aimed to fulfill a multiplicity of needs. This will be a major challenge for politicians, policy makers, local communities, and researchers in the next few decades. New approaches to designing and supporting local water service organizations will need to be considered, getting away from single-purpose “irrigation districts” or informal “water user associations,” to developing user-based entities with sufficient legal and political powers to be effective.

Transcending the infrastructure dependency-deterioration trap

In the years to come, it is likely that governments around the world will continue to devolve responsibility for water management to users. New management models will evolve and new relationships between the state and the locality will develop. Once these systems have been turned over to local organizations, and governments have withdrawn or reduced their subsidies, the sustainability of irrigation infrastructure will remain one of the fundamental issues. This problem is confounded by the conversion of irrigation systems into multiple-use water delivery systems.

Several major constraints to irrigation investment are identified which result in non-sustainable infrastructure:

- high production costs and low profitability of irrigated agriculture
- high cost of irrigation system management
- low water charge collection rates
- lack of a clear policy on responsibility for rehabilitation and modernization
- lack of preventive maintenance or absence of a capital replacement fund
- unwillingness of farmers to finance the full cost of irrigation water, which they see is also being used but not paid for by other users (for domestic needs, fisheries, livestock, small industry, and so on).

Although institutional reform, coupled with strong political will, can overcome these constraints, radical changes will need to be made in the way governments typically relate to farmer organizations if new systems are to succeed. Such reforms must create the right combination of incentives to induce an optimal mix of state and local investment to achieve sustainable infrastructure maintenance.

Implementing integrated water basin management

Today, we readily talk about “integrated water resources management.” Instead of

Halting or reversing environmental degradation is a key element in performance-oriented management of irrigated agriculture.

the usual sectoral approach to developing and managing water resources, integrated water resources management recognizes that river basins are complex systems in which the use of water for one purpose has important implications for other uses. Focusing attention on water basins—a term that includes the upper and lower areas of the basin together with groundwater—enables a systematic approach to managing water, including the socio-technical, economic, and human aspects of water. Importantly, this integrated approach questions the many assumptions we hold, such as those related to “efficiency.” Classical efficiency considers water flowing into drains as a “loss.” But, because of reuse further down the basin, one person’s wasted drainage water is another’s vital water

resource. While efficiencies at field level in a basin may be low, the overall effective efficiency of the basin may be quite high, and the “real” opportunities to save water by improving “efficiency” may be limited.

This will be particularly so in the case of “closed” water systems—where all useable flows are captured and distributed. As population and economic growth increase the demand for water, basins evolve from being “open”—where unused water is still available for additional uses—to being “closed.” Most water basins in arid areas, and many basins in non-arid areas, are becoming closed basins. This has important policy implications. For example, as upstream uses reduce the quality or quantity of flows downstream, different users

Policy makers need to focus on developing water rights that protect the needs of all citizens, especially poor farmers.

become increasingly interdependent. Managing this interdependency is an important public function that few developing countries, as yet, are equipped to handle. It is difficult to develop effective institutional mechanisms to manage water systems, particularly where political or administrative boundaries do not coincide with watershed boundaries, or where competing partisan interests are powerful and entrenched.

Because river basins are complex socio-technical and physical systems, even when there is ample water to meet all demands, they are not easily managed effectively. Once basins become closed, the institutional and management issues become enormously complex. Solutions that seem optimal from a "systems" or "economic" perspective,

may be quite unsatisfactory from a particular water user's perspective. What is required are effective institutional arrangements for establishing the rules of the game, and regulating behavior to ensure the rules are followed to provide the diverse water services demanded by the users.

Three institutional solutions have been suggested to allocating scarce water in basins:

1. *Market allocation:* Treating water as a private "economic good" and enabling its allocation to the highest value through a competitive free market.
2. *Administrative allocation:* The government retains the rights to water.

3. *User-based or “collective action” mechanisms:* User groups hold property rights in water.

IIMI's planned research on these issues for the next few years will take a functional approach. The starting point is the assumption that there are a limited number of essential tasks that must be executed for sustainable and productive management of water basins:

- water resources policy and regulation functions (e.g., policy, planning, research, regulation)
- water service delivery functions (e.g., design, construction, operation, maintenance)

Designing, implementing, and strengthening effective water basin institutions will require considerable experimentation and innovation in the twenty-first century. These innovations are likely to be most effective if they are based on a decentralized, basin-oriented approach that includes representation of stakeholders in their governance. While much can be learned from the experience of wealthy countries, none of these operate under the circumstances in which poor countries find themselves: insufficient financial and human resources combined with weak institutions, inadequate legal systems, and severe social inequality. Changing

these conditions is a necessary step towards the effective but formidable task of managing water in water-scarce basins.

What the future demands from today

To create the institutional requirements for equitable and efficient use of scarce water, policy makers need to focus on developing water rights systems that protect the basic needs of all citizens. In defining water rights, there must be an official and overt recognition of the multiple uses of water, and the multiplicity of legitimate users on any water supply system. This will involve limiting the extent to which water rights in irrigation systems are attached to the land.

The entity providing the water service should be separate from the entity regulating and monitoring water resources allocation. It should be financially autonomous and accountable to all users, and operate according to transparent service agreements. However, in very few developing countries have such emerging institutional requirements been satisfied. This gap is a measure of the challenge facing the water sector in the future and such major changes will require dramatic investments in political will.

Finance and Administration 1997

In 1997, IIMI spent US\$9.94 million from income and \$0.146 million from reserves as operating expenditures (figure 18). The total expenditure was US\$10.09 million of which 74 percent was devoted to research (figure 19). The institute

ended the year with a net operating deficit of US\$0.146 million. Unrestricted donor income in 1997 amounted to US\$3.8 million (table 3) or 38 percent of the total donor funding.

Figure 18. Operating expenditure, 1994–1997.

Figure 19. Research and governance expenditure, 1997.

In 1997, the Institute had 20 senior internationally recruited staff. They were complemented by 16 associate staff (seconded by donor organizations) and postdoctoral fellows. National professional and management staff

engaged in IIMI's research, training, and information activities in headquarters and overseas units numbered 115. IIMI's total staff numbered 356, more than half of them based outside Sri Lanka.

Table 3. Unrestricted, agreed agenda, and non-agenda 1997.

Donor		Grant (US\$)
Unrestricted	Australia	116,055
	Brazil	30,000
	China	10,000
	CIDA	169,169
	Denmark	320,000
	Ford Foundation	350,000
	Germany	284,346
	India	37,500
	Japan	290,363
	Mexico	30,000
	Netherlands	203,951
	USAID	414,000
	World Bank	1,200,000
		<hr/> 3,455,384
Other Revenue	Bank interest	48,241
	Profit on sale of units	216,909
	Sundry income	28,340
		<hr/> 293,490
		<hr/> 3,748,874

Continued.

Table 3. *Unrestricted, agreed agenda, and non-agenda 1997 (continued).*

Donor	Project	Grant (US\$)
Agreed Agenda		
ADB	Second Irrigation Systems Improvements Project (SISIP)	26,118
AFDB	Irrigation Management Development: Niger	51,926
DANIDA	Gender Issues	17,458
DANIDA	Health and Irrigation Study	73,654
DANIDA	Health and Irrigation Study	78,468
DANIDA	Contribution for Workshop	41,544
DFID	Social Organization for Improved System Management and Sustainable Irrigated Agriculture	75,153
EU	Support for IIMI's Research Programs	639,292
Ford Foundation	Nepal IMPT Evaluation	63,276
Ford Foundation	Support for Collaborative Research on Transfer of Irrigation Systems in Mexico	45,934
Ford Foundation	Support for Two Scholars from India	694
Ford Foundation	Water Resources Management	111,812
France	Senior Staff Secondment	207,000
France	Support for IIMI's Program	100,160
France	Support for Pakistan Program	19,396
Germany	Privatization and Turnover	195,965
Germany	Support Systems for Local Management in Irrigation	323,074
IDB	Andean Regional Project	108,588
Iran	Support for IIMI's Research Program	15,986
Japan	Performance Program	286,841
Japan	Environment Program	233,692
Japan	World Climate Atlas	77,453
Japan	Program for Young Scientists (M)	47,833
Japan	Program for Young Scientists (T)	27,734
Japan (MAF)	Soil Salinity Activity	1,561
Japan (JIRCAS)	Optimal Use of Water	24,177
Netherlands	Managing Irrigation for Environmentally Sustainable Agriculture—Pakistan	755,111
NORAD	Design of Environmental Management	5,382
SIDA	Women and Water Workshop	26,391
USAID	World Climate Atlas	36,000
USAID	Shared Control of Natural Resources (SCOR)	911,617
World Bank	Collaborative Research Support Services with GDRS: Turkey	
World Bank/ Pakistan	Fordwah Eastern Sadiqia (South) Project	37,717
World Bank/Swiss	LBOD Project	568,982
		133,332
	Subtotal	5,369,321

Table 3. Unrestricted, agreed agenda, and non-agenda 1997 (continued).

Donor	Project	Grant (US\$)
Agreed Agenda		
Australia	System-Wide Initiative on Water Management	24,378
DANIDA	System-Wide Initiative on Water Management	114,015
Denmark	System-Wide Initiative on Water Management	61,402
Ford Foundation	System-Wide Initiative on Water Management	75,000
Germany	System-Wide Initiative on Water Management	57,468
Netherlands	System-Wide Initiative on Water Management	129,625
	Subtotal	461,888
	Subtotal agreed agenda	5,831,209
	Total core	9,580,083
Non-Agenda		
ADB	Pehur High-Level Canal Project	11,064
Ford Foundation	Workshop at IICA	9,627
Ford Foundation	Research, Training & Meetings on Irrigation Management (Mexico)	25,238
IFAD	Participatory Rural Development Project for North Central Province	10,791
USAID	Shared Control of Natural Resources (SCOR)	303,872
	Subtotal non-agenda	360,592
	Total	9,940,675

**Consolidated Statement of
Financial Position at 31 December 1997**

	1997 US\$'000	1996 US\$'000
Assets		
Current Assets		
Cash and cash equivalents	2,750,759	4,121,543
Accounts receivable:		
Donors	2,547,141	1,044,613
Employees	59,082	79,732
Others	72,516	192,147
Inventory	42,686	59,672
Prepaid expenses	244,048	299,861
Total current assets	5,716,232	5,797,568
Collateral for PRI loan	589,336	574,245
Fixed Assets		
Property, plant, and equipment	5,165,394	5,034,517
Less: Accumulated depreciation	3,040,640	2,877,521
Total fixed assets-Net	2,124,754	2,156,996
Total Assets	8,430,322	8,528,809
Liabilities and Net Assets		
Current Liabilities		
Contribution received in advance	977,205	1,179,454
Other accounts payable	1,041,246	642,843
Accrued expenses	100,591	45,877
	2,119,042	1,868,174
Provision for Liabilities & Charges		
Severance/gratuity benefits	286,850	307,032
International staff repatriation	222,979	184,994
International and national staff unutilized leave provision	146,073	186,943
	655,902	678,969
Long-Term Debt		
PRI loan	148,825	296,171
Total Liabilities	2,923,769	2,843,314
Net Assets		
Capital invested in fixed assets:		
Center-owned	1,765,141	1,559,578
In custody	98,331	190,288
Capital fund	1,163,251	1,202,605
Operating fund	1,890,494	2,158,779
Collateral for PRI loan	589,336	574,245
Total Net Assets	5,506,553	5,685,495
Total—Liabilities and Net Assets	8,430,322	8,528,809

Source: 1997 Audited Accounts.

RESTRICTED PROJECTS 1997

Project	Donor	Pledged amount*	Duration (months)	Cumulative expenditure* to 31/12/1996	Expenditure* 1997
Agreed Agenda Grants					
Second Irrigation Systems Improvements Project (SISIP) To reduce poverty among the target beneficiaries by increasing family income through increased agricultural productivity.	Asian Development Bank	206,745	48	Nil	26,118
Niger Evaluation of performance of farmer-managed irrigation systems in the Niger river valley.	African Development Bank	1,186,500	84	1,126,404	51,926
Gender Issues in Irrigation Management Increase the knowledge and understanding of gender issues in irrigation, especially the role of women in irrigated agriculture as well as its impact on women's lives.	DANIDA	59,985	36	42,527	17,458
Health and Irrigation Project Support to continue work on IIMI's Health and Irrigation Project.	DANIDA	87,986	12	14,332	73,654
Health and Irrigation Project Support to continue work on IIMI's Health and Irrigation Project.	DANIDA	94,095	12	Nil	78,468
Contribution for Workshop Irrigation development for the improvement of the health status of irrigation communities.	DANIDA	48,985	12	Nil	41,544
Holdback Project R6415(H) Social organization for improved system management and sustainable irrigated agriculture.	DFID	Sterling Pounds 148,420	36	38,318	75,153

*In US dollars unless otherwise stated.

Continued.

Project	Donor	Pledged amount*	Duration (months)	Cumulative expenditure* to 31/12/1996	Expenditure* 1997
Research Support Improving food security and the lives of poor people by fostering sustainable increases in the productivity of water used in agriculture through better management of irrigation and water basin systems.	EU	ECU 1,180,000	12	549,652	639,292
Monitoring and Evaluation Activities in Nepal Support for studies on transfer of irrigation systems in Nepal.	Ford Foundation New York	230,500	36	5,656	63,276
Mexico Phase II Support for collaborative research on transfer of irrigation systems in Mexico.	Ford Foundation New York	200,000	24	154,066	45,934
India Support for the participation of two scholars from India for the Women and Water Workshop.	Ford Foundation New York	2,500	12	Nil	694
Water Resources Management Determining the impact of changes in irrigation and water resources management in Mexico.	Ford Foundation New York	280,000	12	Nil	111,812
Senior Staff Secondment Support for staff secondment.	France	207,000	12	Nil	207,000
Support for IIMI's Program Support for research on the operation of irrigation for systems in Sri Lanka.	France	100,160	12	Nil	100,160
Support to Pakistan Support for research activities on application of GIS & RS in the land use mapping and technology transfer.	France	27,035	12	Nil	19,396
Privatization and Self-Management of Irrigation Conducting research and development programs for turnover in selected countries.	Germany	DM 700,000	24	219,781	195,965

*In US dollars unless otherwise stated.

Continued.

Project	Donor	Pledged amount*	Duration (months)	Cumulative expenditure* to 31/12/1996	Expenditure* 1997
<i>Program of Support Systems for Local Management in Irrigation</i> Defining the critical elements necessary for sustainable local management of irrigation systems.	Germany	DM 1,651,115	36	735,873	323,074
<i>Andean Regional Project on Irrigation and Environmental Management</i> Helping irrigation agencies assess the environmental impacts arising from the expansion of upstream irrigation.	Inter-American Development Bank	500,000	27	391,412	108,588
<i>Support for IIMI's Program</i> Support for joint research activities between the AREEO & IIMI.	Iran	74,927	24	Nil	15,986
<i>Performance and Impact Assessment Program</i> Support for research to improve the performance of irrigated agriculture.	Japan	Yen 34,825,000	12	Nil	286,841
<i>Health and Environment Program</i> Support for the environment program and to measure and quantify environmental impacts of irrigation.	Japan	Yen 35,451,720	12	Nil	233,692
<i>World Climate Atlas</i> Providing climatic data for any point on the earth's land surface based on 30 years of climatic and water data.	Japan	Yen 21,611,000	12	Nil	77,453
<i>Program for Young Scientists (M)</i> Support for Japanese research officers at CGIAR research institutes to work in IIMI's Environment Program.	Japan	90,000	12	30,916	47,833
<i>Program for Young Scientists (T)</i> Support for Japanese research officers at CGIAR research institutes to work in IIMI's Environment Program.	Japan	45,000	12	Nil	27,734
<i>Soil Salinity Activity</i> Identifying primary factors contributing to soil salinity in Sri Lanka and Pakistan.	Japan (MAF)	5,000	12	Nil	1,561

*In US dollars unless otherwise stated.

Continued.

Project	Donor	Pledged amount*	Duration (months)	Cumulative expenditure* to 31/12/1996	Expenditure* 1997
<i>Optimal use of Water</i> Developing the optimal water management under water-deficit conditions for crop diversification.	Japan (JIRCAS)	30,800	12	Nil	24,177
<i>Gender Issues in Irrigation Management</i> Increasing knowledge and understanding on the relationship between gender relations and the performance of irrigation systems.	Netherlands	DFL 300,600	60	141,509	Nil
<i>Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan</i> Support for studies on salinity and waterlogging.	Netherlands	NLG 5,752,000	51	1,635,759	755,111
<i>Design and Environmental Management Interventions for Vector Control</i> Support for research on reducing the transmission of vector-borne diseases in irrigated areas.	NORAD	50,985	19	45,603	5,382
<i>Women and Water Workshop</i> A workshop on gender and water management.	SIDA	26,391	8	Nil	26,391
<i>World Climate Atlas</i> Providing climatic data for any point on the earth's land surface based on 30 years of climatic and water data.	USAID	36,000	12	Nil	36,000
<i>Shared Control of Natural Resources (SCOR)</i> Assisting Sri Lanka to sustain the productivity of land and water resources within selected watersheds through shared control by local user groups.	USAID	5,995,800 (Sri Lanka Rs 22,875,000)	64	3,418,821	1,215,489
<i>Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project</i> Research and monitoring activities through the membership of the Umbrella Technical Group and for the preparation of an Integrated Research Plan.	World Bank/ Pakistan	367,116 (Pakistan Rs 2,442,600)	60	127,439	37,717

*In US dollars unless otherwise stated.

Continued.

Project	Donor	Pledged amount*	Duration (months)	Cumulative expenditure to 31/12/1996	Expenditure 1997
<i>Supplementary Project for Strengthening of Left Bank Outfall Drain (LBOD) Stage-I</i> Testing the viability of farmers' management of irrigation systems, for efficient and equitable allocation of water.	World Bank/ Swiss Development Corporation	695,089 (Pakistan Rs 19,068,798)	30	669,644	568,982
<i>Collab. Research Support Services with DGRS: Turkey</i> Improving the capacity of the soil and water research institutes of GDRS to undertake research relevant to Turkey's priorities.	Turkey	800,000	24	Nil	133,332
<i>System-Wide Initiative on Water Resource Management</i> Research on natural resource management and agriculture, to make more rational use of fresh water.	Australia DANIDA Denmark Ford Foundation Germany Netherlands	24,378 114,015 61,402 75,000 57,468 129,625	12 12 12 12 12 12	Nil Nil Nil Nil Nil Nil	24,378 114,015 61,402 75,000 57,468 129,625
<i>Non-Agenda Grants</i>					
<i>Pehur High-Level Canal Project</i> For joint activities involving the Irrigation Department, the Government of the North-West Frontier Province, and IIMI.	Asian Development Bank	487,797 (Pakistan Rs 10,553,119)	84	50,862	11,064
<i>Irrigation Management Issues</i> For partial support for research on irrigation management issues.	Ford Foundation New York	27,500	30	17,873	9,627
<i>Mexico</i> Support for research, training, and meetings on irrigation management in the US-Mexico border area.	Ford Foundation New York	55,000	24	Nil	25,238
<i>North Central Province Participatory Rural Development Project-Supplementary Study: Small Tank Cascade Study</i> A regional economic development study; an institutional and human resources study.	IFAD	100,000	17	84,600	10,791 <hr/> 6,191,801

*In US dollars unless otherwise stated.

DONORS 1997

During 1997, IIMI's funding support was provided by the following governments, development banks, agencies, and foundations:

- Australia
- Brazil
- Canada
- China
- Denmark
- European Union
- France
- Germany
- India
- Iran
- Japan
- Netherlands
- Norway
- Philippines
- Spain
- Sweden
- Turkey
- United Kingdom
- USA
- African Development Bank
- Asian Development Bank
- Inter-American Development Bank
- World Bank
- Ford Foundation
- International Fund for Agricultural Development

The Governments of Bangladesh, Burkina Faso, Colombia, Egypt, India, Mexico, Nepal, Niger, Pakistan, and Sri Lanka provided program support for IIMI-related activities in those countries.

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SELECTED PUBLICATIONS 1997–1998

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district. *International Journal of Water Resources Development* 14(2):231-247.

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Vermillion, D. L. 1998. Impacts of irrigation management transfer: Results from IIMI's research. *INPIM* 7:1-3; 12-13; 21.

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