Governance for Integrated Water-Resources Management in a River-Basin Context

Governance for Integrated Water-Resources Management in a River-Basin Context: Proceedings of a Regional Seminar, Bangkok, May 2002

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INTERNATIONAL WATER MANAGEMENT INSTITUTE

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Cover photo, by B. R. Ariyaratne, shows sand deposits in the Deduru Oya river, Sri Lanka.

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Contents

Foreword

This volume presents the proceedings of the regional seminar on institutional arrangements for river-basin management organized by the International Water Management Institute (IWMI) in collaboration with the International Food Policy Research Institute (IFPRI) and the Kasetsart University (KU) in Bangkok and held in Bangkok, Thailand from 21 to 23 May 2002. The seminar marked the culmination of a 4-year research project on *Developing Effective Water Management Institutions* funded by the Asian Development Bank (ADB) conducted by IWMI in association with national agencies, initially in selected river basins in China, Indonesia, Nepal, Philippines, Sri Lanka and subsequently in two river basins in Thailand in collaboration with the Kasetsart University and the Office of the National Water Resources Committee of Thailand.

The 3-day event had two components: the seminar on the theme *Governance for Integrated Water-Resources Management in a River-Basin Context*, and *a Ministerial Roundtable Dialogue on Water-Sector Challenges, Policies and Institutional Development in Asia*. This volume contains papers presented at the seminar. Proceedings of the ministerial dialogue are published in a separate volume.

The seminar was convened to present and discuss the results of studies conducted by IWMI and IFPRI in selected river basins in Asia. The studies conducted by these institutes were supported by the ADB; these studies shared some common goals, and encompassed work plans and methodologies that were complementary and mutually supportive. Six papers were presented, four on IWMI's research studies and two reporting the results of the IFPRI studies.

The overall goal of IWMI's study was to improve the management of scarce water supplies available for agriculture, within a framework of integrated water resources management (IWRM) in a river-basin context. The specific objective was to develop and initiate the implementation of policies and institutional strengthening programs aimed at realizing the overall goal. The IFPRI study, "Irrigation Investment, Fiscal Policy, and Water Resource Allocation in Indonesia and Vietnam," had two major objectives. One was to improve IWRM at the river-basin level through an analysis of water-allocation mechanisms and institutional structures. The analysis included the impacts of investments in irrigation and water-resources development, reform of pricing and taxation policies, and improvement in water-allocation mechanisms. The other major objective was an assessment of the impacts of agricultural taxation, water pricing, and public expenditures on irrigation and water resources. The core of IFPRI's regional study was the development of river-basin models for the Dong Nai river basin in Vietnam and the Brantas river basin in Indonesia, supported by an analysis of the effects of national fiscal and investment policies on water-resources planning.

The collection of papers in this volume is organized into three parts. It begins by laying the conceptual foundation for IWRM followed by the elaboration of the perspectives on IWRM in a river-basin context. This is followed by papers on the results from the case studies on institutional arrangements for water management in the selected basins. Other topics discussed are alternative water-policy scenarios using integrated river-basin modeling based on the Brantas river basin, Indonesia and a discussion on water allocation and use in the

Dong Nai river bsin, Vietnam. The final part provides a synthesis of the results from IWMI's five-country study and concludes with a general summary of the papers presented at the seminar.

The common thread running though all these papers is that while the need for effective management of river basins is well recognized, in most settings, river-basin institutions are in an embryonic stage of development. More substantial work needs to be done, designing effective institutional arrangements for managing river basins. It is hoped that the lessons from these five basin studies will provide useful information towards this end.

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Acknowledgements

This publication, and the research work leading to it, are strongly based on collaborative work. Our thanks should first go to the heads of collaborating agencies in the six countries and the authors of individual papers published in this volume.

In April 2001, IWMI opened its South East Asia Regional office in Bangkok, Thailand. The office is currently hosted in Thailand through a Memorandum of Understanding between IWMI and the Kasetsart University (KU), Thailand's premier agricultural university. Since the establishment of this IWMI SEA Office, IWMI has been developing a collaborative program of research with KU to cover areas of mutual interest. The May 2002 *Regional Seminar on Governance for Integrated Water-Resources Management in a River-Basin Context* marked a significant development in this collaborative relationship. A team of researchers from IWMI collaborated with a KU team of researchers to undertake a rapid appraisal of two river basins in Thailand, and this activity formed part of IWMI's multi-country institutional studies in a river-basin context. When this final regional seminar was planned for the overall study, KU's active collaboration as a coorganizer of the seminar helped IWMI to organize the event successfully. Their collaborative support is gratefully appreciated.

IWMI's sister organization, the International Food Policy Research Institute (IFPRI), participated in the regional seminar to share the results of its basin studies in Vietnam and Indonesia. IFPRI researchers were accompanied by their counterparts from the two countries. IWMI would like to thank all these partners, who helped make this study a productive effort.

The multi-country study, the final regional seminar and this publication were all sponsored by the Asian Development Bank (ADB) through funds made available in the Regional Technical Assistance Program (RETA) No. 5812. The Bank's financial assistance was complemented by the guidance and support provided by its program staff, particularly, ADB's Lead Water Resources Specialist, Mr. Wouter T. Lincklaen Arriens, and Project Engineer, Mr. Ken Yokoyama. IWMI would like to extend its gratitude to them for giving continued support to undertake the study activities. Finally, we would like to thank Mr. Kingsley Kurukulasuriya for his meticulous efforts in editing all the papers in this volume for publication in a very short period of time.

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Part 1

Introduction

"Water for All": A Conceptual Foundation for Integrated Water Resources Management[1]

D. J. Bandaragoda[2]

Water is one natural resource for which all human beings are stakeholders. All people, irrespective of gender, age, social status, location, educational level, job or economic status, need water and invariably use water in various ways. Therefore, all have a stake in water, and need to be concerned about how water resources are managed and used.

Of all the water on the earth, approximately 97.5 percent is salty, and of the remainder, about 70 percent is frozen in polar ice caps. It is rather unbelievable, but is true that less than 1 percent of the world's freshwater, or 0.007 percent of all water on earth, is accessible for direct human use (Shiklomanov 2000, 11).

Global demand for water rose by six to seven times over the last decade, more than double the rate of population growth. This means that average water use is becoming increasingly intensive. As economic development increases and urbanization expands, human needs for water increase and, coupled with population increases, the demand for freshwater is spiraling upward. The world's population is estimated to grow to around 10–12 billion by 2050. With this kind of scenario, it is of paramount importance to consider how best we can devise ways and means of using water judiciously, equitably and economically, and make available adequate amounts of water for all users.

Recognizing the need for water available for myriad uses, the Asian Development Bank (ADB) has introduced the inspiring motto: "Water for All." Premised on Asia's urgent need for integrated approaches to water management, ADB's policy seeks to promote seven key requirements (ADB 2001):

i. a national focus on water-sector reforms

ii. integrated management of water resources (IMWR)

iii. improved and expanded delivery of water services

iv. water conservation and increased system efficiencies

v. regional cooperation and mutually beneficial use of shared water resources within and between countries

vi. exchange of water-sector information and experiences

vii. improved governance

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[1]This brief paper is based on the introductory remarks presented at the Regional Seminar on "Governance for Integrated Water Resources Management in a River Basin Context," held in Bangkok in May 2002.

[2]Director, IWMI Southeast Asia Regional Office, and Project Leader for the Study on Development of Effective Water Management Institutions.

The International Water Management Institute's (IWMI's) study on "Developing Effective Water Management Institutions" was strongly founded on the abovementioned criteria, and entered into the vast area of the water-related concerns in a small way. Conducted only in seven selected river basins in six countries in Asia, the study could not attempt to make universal generalizations. However, at this concluding stage, the study could highlight some critical issues:

- In any given river-basin area, each water user group (such as irrigation, domestic water supply, power generation or industry) is almost completely unaware of the scope of water use by the other user groups.
- The users in any particular sector, as well as related agencies dealing with that sector, are almost completely sector-oriented. There is very little consultation with others in designing and implementing infrastructural development, or in subsequent management phases.
- If there is any information collected by a particular user group, that information is invariably kept within that group and not made available in the public domain.
- As seen in the seven selected river basins, the concept of river-basin management, or of IWRM in a river-basin context, is rarely practiced in developing countries. None of the basins studied had a river-basin organization of any kind, nor was there any serious preparation to introduce such management systems until the study interventions began to have an impact.
- In all the river basins studied, there is a felt need to coordinate among the various water user groups, including the functions of water allocation, information handling, water-management practices, and related mechanisms for conflict management.
- The study was able to effectively mobilize stakeholder interest in introducing coordination mechanisms for river-basin management.
- The study also concludes that the degree of development in a river basin is the main criterion that should determine the need for, and the appropriate type of, organization for river-basin management.

Many other study outcomes were presented during the course of the final regional seminar. The objective of the study would be to convert these outcomes to some program of action in each participating country for achieving the goals of IWRM.

The first regional workshop of the study, held in Colombo, Sri Lanka, in July 1999, finalized the inception activities and methodologies for this study. In January 2001, the second regional workshop was held in Malang, Indonesia, to discuss field work conducted in selected river basins of five countries: China, Indonesia, Nepal, Philippines and Sri Lanka. The final regional seminar for this study was held in Bangkok, in May 2002. It was not only a happy family reunion for all of those who had been involved in the study since 1999, but also a dialogue in which an attempt was made to sort out some action plans implementable on a long-term basis.

"Water for All" also has a connotation of water for all purposes. While water, as a social and economic good, can be considered as central to human existence, as a natural resource, it can also be perceived as an integral part of the ecosystem. Viewed in the context of river basins, the value of the concept of IWRM can be further appreciated. The main thrust of this multi-country river basin study is to highlight this concept, and the theme of the final regional seminar of the study has thus been called "Water for All."

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Governance Issues in River-Basin Management: A Regional Perspective

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Introduction

Water governance refers to the "range of political, social, economic and administrative systems that are in place to regulate the development and management of water resources and provision of water services at different levels of society." Effective water governance is concerned with how water resources are managed, and who manages them, i.e., the mandates, controls, rights and responsibilities of the different stakeholders in water utilization and management, and the relations between the different stakeholders in practice. The term "good governance" is avoided because it is value-laden and because there is no single model of effective governance. To be effective, governance systems must fit the social, economic and cultural peculiarities of each country.

Effective Water Governance

The effectiveness of a governance approach follows several fundamental principles, as follows:

- *Transparency.* An atmosphere of transparency wherein decisions are made in a comprehensible, open manner creates more trust and confidence within the system. Transparency likewise implies that the relevant information is circulated and made available to all stakeholders, and informed decision making is always sought.

- *Accountability.* Good governance bestows responsibility and accountability over decisions and resources, and provides for consequences (e.g., rewards, penalties) for outcomes.

- *Equity.* The equity principle seeks to address social, economic, political and geographical disparities among water users, by consciously incorporating the concepts of water needs and water rights, and by addressing the needs of the disadvantaged, including gender issues, in water management.

- *Participation.* A genuine participatory approach, whereby stakeholder representatives starting at the grass-roots level, increases the practicability and sociopolitical acceptability of water-management projects.

- *Communications.* A crosscutting concern, effective communications increase transparency in water governance and provide strong feedback mechanisms particularly for civil society and grass-roots organizations.

- *Incentive-based approach.* Rather than penalizing negative results, an incentive-based approach to water governance encourages positive, creative actions, and minimizes costs of water management by avoiding poor decisions or actions that could require expensive rehabilitative or reparative measures.

- *Coherence.* A rational and consistent approach to water governance, which constantly seeks consensus, integration and equity, and delivers a strong message that is easily understood and accepted by water users and stakeholders.

- *Efficiency.* Good governance promotes efficiency by streamlining procedures and processes, and reduces bureaucracy.

- *Integration.* A key strategy to improve efficiency in water governance, integration involves clear coordination among and within disciplines, geographical areas, organizational structures within and outside of governments, and administrative boundaries.

- *Ethics.* Often the most overlooked aspect of governance, ethics provides the social framework for water governance. In many societies, particularly in old, traditional societies in Asia, ethics provides strong foundations for good water practices and good governance.

An effective governance for water must be able to: a) create an enabling environment that facilitates efficient private and public-sector initiatives; b) provide regulatory regimes allowing clear transactions between stakeholders in a climate of trust; and c) encourage shared responsibilities for safeguarding river and aquifer resources.

Governance Dialogues

The governance dialogues take their roots from the Second World Water Forum in The Hague, The Netherlands, wherein the GWP Framework for Action stated that "the water crisis is often a crisis of governance." The Hague Ministerial Declaration further reinforced this view and called for "governing water wisely to ensure good governance, so that the involvement of the public and the interests of all stakeholders are included in the management of water resources." Likewise, during the 2000 UN Millennium Assembly, Heads of States emphasized conservation and stewardship in protecting our common environment, especially to "stop the unsustainable exploitation of water resources, by developing water-management strategies at the regional, national and local level, which promote both equitable access and adequate supplies." During the Bonn Freshwater Conference in 2001 the Ministers further recommended action in three areas with water governance as the most important, proposing that "each country should have in place applicable arrangements for the governance of water affairs at all levels, and where appropriate, accelerate water sector reforms."

For Southeast Asia, national and regional dialogues on water governance are therefore being convened by the GWP Southeast Asia Technical Advisory Committee (GWP SEATAC), often in partnership with country water partnerships, national governments, and external support agencies to promote and facilitate the adoption of effective water-governance models.

Governance Issues in River-Basin Management

At the river basin, governance issues may be classified according to three major components: policy, institutions and management tools.

- *The role of policy.* Water-management policies provide the enabling legal and political bases for action on water management. A sound policy environment is highly dependent on three major factors: a) strong political will and decision making; b) decentralization and transfers of tasks; and c) provision of responsive water laws.
- *The role of institutions.* The institutional structures serve as the medium and implementation arm for good water governance. Obviously, good policies without good institutional support cannot be successful. Sound institutional support may be characterized by a) adequate representation of a wide range of stakeholders; b) flexibility; and c) representation of the grass-roots sector.
- *The role of management tools.* Management tools are the instruments and/or mechanisms by which institutional bodies carry out and apply the general and specific policy declarations. To be applicable, management tools should a) be based on clear delegation of responsibilities; b) have technical and financial support; c) be supported by an information network; d) promote capacity building; and e) assign clear authorities with regard to the monitoring and control of budgets and plans.

At the river basin therefore, the provision of a water-management framework that encompasses all three major components described above will result in a higher probability of success for a more sustainable water-resources management.

Perspectives on Integrated Water-Resources Management in a River-Basin Context

Eric Biltonen, Ph.D.[1]

Introduction

The water resources of Asia have been coming under increasing pressure on a number of different fronts. In general, these pressures have led to a decrease in the availability of water in terms of quality and quantity. In turn, because water is a critical element of life and many livelihoods, a decrease in the availability will affect all stakeholders. It has become increasingly recognized that no longer can a single sector pursue the management and use of water resources without either being impacted by, or affecting, the management and use of water in another sector. Furthermore, the intimate linkage of upstream and downstream conditions requires effective water management to be approached from a basin perspective. The recognition of the many linkages and interdependencies has led to the development of the concept of Integrated Water Resources Management (IWRM). This paper offers a review of these linkages, of the concept of IWRM, and how the many linkages lead to the need for IWRM. The paper closes with some guiding thoughts to consider in regard to IWRM.

Water Resources

Water as a natural resource is necessary for livelihoods, irrigation, production, hygiene, sanitation and life. The importance of water as a central element to life has been explicitly placed in policy statements of many donors and development agencies (WB 1993; ADB 2000; WSSCC 2000). Water resources play an especially critical role in agriculture, on which many of the region's poorest people depend. Agriculture is also the largest bulk user of water resources among all the users. However, agriculture is often the least influential sector in the management process, especially individual farmers. Water resources are impacted in a number of different ways including how water is used, how water is governed, and the condition of the ecosystem of which the water resources are a part.

Uses

Each use of water affects the quantity and quality available to be returned and made available for other uses. It is necessary to limit the harm done to both the quality and quantity of water.

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It has been recently stated that water "scarcity is caused by people not having access to enough water. It is not caused by there not being enough water " (Soussan 2002).

Governance

Governance deals with the authority and decision making that impact on how water is developed and managed (Global Water Partnership 2002). Of special importance is the range of stakeholders who have been empowered to participate in the decision-making process. Governance is a multidimensional concept involving the processes for water management, the people who are able to participate, and the stability of society and government.

Ecosystem

The ecosystem refers to the natural system through which water passes. The ecosystem and the water resources are mutually dependent. While the ecosystem depends on water flows as they occur over time, water resources depend on a healthy ecosystem. The ecosystem includes water, land and forest resources. Degradation of any part of the ecosystem can damage the water resources. Therefore, it is critically important to consider adverse impacts on these natural resources when making management decisions (GWP-TAC 2000).

Individual impacts in any one of the above categories can be linked with impacts in any other category. For instance, problems of pollution can be seen to be a result of water being used as a waste sink, as a result of poor regulation of pollution emissions, and as degradation of the ecosystem. The interaction of the many elements under each category has led to increased variability in availability, increased risk of water-related natural disasters, and decreased quantity and quality of available water. In fact, the linkage of these many impacts has been a primary motivating factor in moving to an IWRM approach.

The 1992 Dublin Principles are an early example of the IWRM approach. The principles illustrate the main issues confronting water management (Solanes and Gonzalez-Villarreal 1999). The principles are stated as follows:

- *Principle No. 1.* Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.
- *Principle No. 2.* Water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels.
- *Principle No. 3.* Women play a central part in the provision, management and safeguarding of water.
- *Principle No. 4.* Water has an economic value in all its competing uses and should be recognized as an economic good.

These four principles address issues of scarcity, the need to govern effectively, the need to involve stakeholders in management, and the need for instruments to regulate water use.

Integrated Management

"Integrated" is a word that is likely used more than it is understood. One dictionary entry lists the following three definitions:

1. Combined or composite: made up of elements or parts that work well together.

2. Combining dissimilar things: bringing together processes or functions that are normally separate.

3. Open to all people: open to everyone, without restrictions based on race, ethnicity, religion, gender or social class (Encarta 1999).

No single definition listed above may be discarded in discussing IWRM. Integrated management necessarily involves all relevant sectors such as agriculture, industry, environment, and domestic water supply. Integrated management strives to bring together a wide range of relevant institutions from the many sectors in a cooperative and coordinated manner. Finally, integrated management crosses all social barriers and actively seeks to involve all stakeholders.

When an integrated approach is taken, the stakeholders affected both guide the management process and are impacted by the results of the management process. This creates a cycle of impacts, which may be beneficial or detrimental. Since all stakeholders are actively involved, the management process may be adjusted over time to bring about more favorable impacts. As all stakeholders are being impacted, it is also more important to consider the management objectives, such as efficiency, equity and environmental sustainability. It can be seen that management becomes a *process*, rather than a fixed plan.

IWRM

The Global Water Partnership has become a leading proponent of IWRM. In a recent publication this Partnership put forth the following definition of IWRM. The publication states that:

> IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP-TAC 2000).

It can be seen from this definition that IWRM subscribes to the idea that management is a process. In particular, water management must be carried out in a manner that explicitly recognizes the interdependency of water with the other natural resources. It further embodies the notion of managing water with the goal to maximize economic and social welfare while keeping an eye on equity and the environment.

Some of the key challenges that face the successful implementation of IWRM include issues of:

- securing adequate funding for development and management
- devising effective management of water pollution
- increasing access to safe water for drinking, sanitation and hygiene
- increasing productivity of water to achieve food security
- achieving a more optimal balance of efficiency and equity of water used within a basin
- reducing water-related risks and vulnerability (flooding, droughts and disease)
- promoting sustainable management practices to conserve natural resources and reverse degradation

While a precise solution to the above challenges remains unclear, it is increasingly clear that the highly sectoral and fragmented management approaches of the past are unable to meet these challenges effectively. IWRM is a new approach for managing water that explicitly incorporates the complexities and dimensions of effective water resources management.

Actions by International Agencies

Actions by many governments, donors, development agencies and NGOs confirm the recognition of a need to pursue IWRM. In general, several realizations have come to light. One is the recognition of the river basin as the most effective management scale for water resources. Within the basin, management must assume a much more integrated and comprehensive approach that addresses all sectors and stakeholders. It is essential that all stakeholders actively participate in the management process. Finally, there is the most critical need to motivate the political will to act.

For IWMI's part, the current involvement in the "Study on the Development of Effective Water Management Institutions" project is just one demonstration of IWMI's commitment to IWRM. IWMI is also one of three Global Water Partnership (GWP) Resource Centers. As a GWP Resource Center, IWMI works to match its resources with demands for its knowledge. In performing Resource Center activities, IWMI helps the GWP to meet its objective of supporting countries in their efforts to achieve sustainable management of their water resources.

A Word about Poverty

Recently, poverty reduction has become the primary goal of many development agencies. These agencies recognize poverty as a deprivation of both opportunities and access to resources (UNDP 1997; ADB 1999; WB 2000; Dutch Ministry of Foreign Affairs 2001). Strategies for achieving wide-scale poverty reduction are being developed and pursued with tremendous enthusiasm. Of particular relevance to the current seminar is the increased focus on the link between water and poverty. Water is linked to poverty through sanitation and hygiene (WSSCC

2000), access to irrigation (Hussain and Biltonen 2001), and vulnerability to water-related hazards (Soussan 2002). The proper management of water is more than preserving the environment or making efficient use of a scarce resource; it is most importantly about improving the lives of people, particularly of the poor. Recently, a Water and Poverty Initiative was begun with the aim to promote the importance of achieving water security to improve the lives of the poor.[2] The initiative seeks to do this by building awareness, exchanging experience and knowledge, and catalyzing pro-poor funding and policy development.

Guiding Thoughts for the Seminar and Beyond

The purpose of this seminar is to present and discuss our research findings on governance for IWRM in a river-basin context. The results of the research can indicate areas where generic lessons on good governance, which are based on real experience, can be gained. The seminar can also offer a better understanding of what "integrated management" really means. This integration requires a management process that includes numerous stakeholders, sectors, disciplines and objectives, and occurs across time and space. In looking forward, we need to develop the will and the way to put knowledge into action. Finally, the potential for better water management to improve the lives of the poor is significant. It should be remembered that through every aspect of water management addressed improvement can yield real benefits for those most in need.

[2]The Water and Poverty Initiative is being led by the ADB with activities leading to the 3rd World Water Forum.

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Part 2

River-Basin Studies

Water-Resources Management in the Upper Inderagiri River Basin, West Sumatra, Indonesia

Helmi and Ifdal[1]

Introduction

The area of the West Sumatra Province falls into six river basins. One of these is the Inderagiri river basin that, according to the Public Works Ministerial Decision on the division of the river territories, is under the authority of the Ministry of Public Works because the basin is located in two provinces. The upper part of the Inderagiri river basin is located in West Sumatra, while the lower part is located in the Riau Province.

The construction and operation of a hydroelectric power plant (HEPP) at Singkarak lake in late 1997 diverted (transferred) water from the Singkarak lake to the Anai river subbasin, from which the water flows to the west coast of Sumatra. Water was diverted to the Anai river to obtain sufficient head to generate power. In the Anai area the altitude is around 10 m above sea level. The diversion changed the water supply for the Ombilin river and affected users along the river. Since then water management in the Ombilin river has become a concern for various stakeholders.

This paper discusses some of the issues involved in the management of the Upper Inderagiri basin, particularly along the Ombilin river. The next sections describe the subbasin, and how the interbasin transfers have affected water availability. The section that follows these two sections analyzes socioeconomic and institutional issues, focusing on the impact of interbasin transfers and developing the framework for water licensing and basin-management organizations. The final section presents an agenda for the development of institutions for integrated water resources management (IWRM) in the context of national policies and activities in West Sumatra.

The Upper Subbasin of Inderagiri River Basin and Its Hydrology

Demography and Employment

The total population occupying the subbasin area in 1997 was 662,425, with an average population density of 408 persons per square kilometer. The urban-rural population ratio is 0.28. This implies that water supply for urban needs will be an important issue in the near future. In 1997, there were 150,466 households in the basin area with an average household size of 4.59 persons. It is estimated that only around 12.56 percent (or some 18,898) households

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are served by pipe-borne water. Many households still need to be served with piped water in the future. Aside from households, there are also some industries, offices and social facilities that are served by piped water.

With regard to employment, around 68 percent (or 94,508 out of 139,831 households) were categorized as farm households. Since more recent data were not available, data from a 1993 agricultural census were used to estimate the number of households engaged in agriculture and nonagriculture sectors. Assuming that the percentage of people engaged in both sectors is the same as before, the number of farm households in the basin area for 1997 would be about 98,000. This number indicates that the majority of the households in the basin area are engaged in agriculture as their main occupation. It is reasonable enough to expect that water demand for agriculture-related activities will be one of the major issues in the basin area.

The Subbasin and Its Area

The Inderagiri river originates from the highlands of West Sumatra and flows to the east coast of Sumatra Island. The upper subbasin of the Inderagiri river basin in the West Sumatra Province consists of three major rivers, Lembang/Sumani, Sumpur, and Ombilin, and two lakes, Danau Dibawah and Singkarak, as figure 1 shows. The altitude in the upper subbasin rises from 164 m above sea level at the lowest point (near the confluence of the Ombilin and the Sinamar rivers) to 1,200 m at the point where the Lembang river originates from the Dibawah lake, which is about 363 m above sea level. Water from the Lembang/Sumani and Sumpur rivers flows into the Singkarak lake, while the Ombilin river originates from the Singkarak lake and flows eastward to the Inderagiri river.

The total area of the upper Inderagiri subbasin was estimated at 3,060 square kilometers. The basin area includes 400 *desa* (villages) within three districts and three municipalities. Of these villages, the majority (around 87%) are categorized as rural.

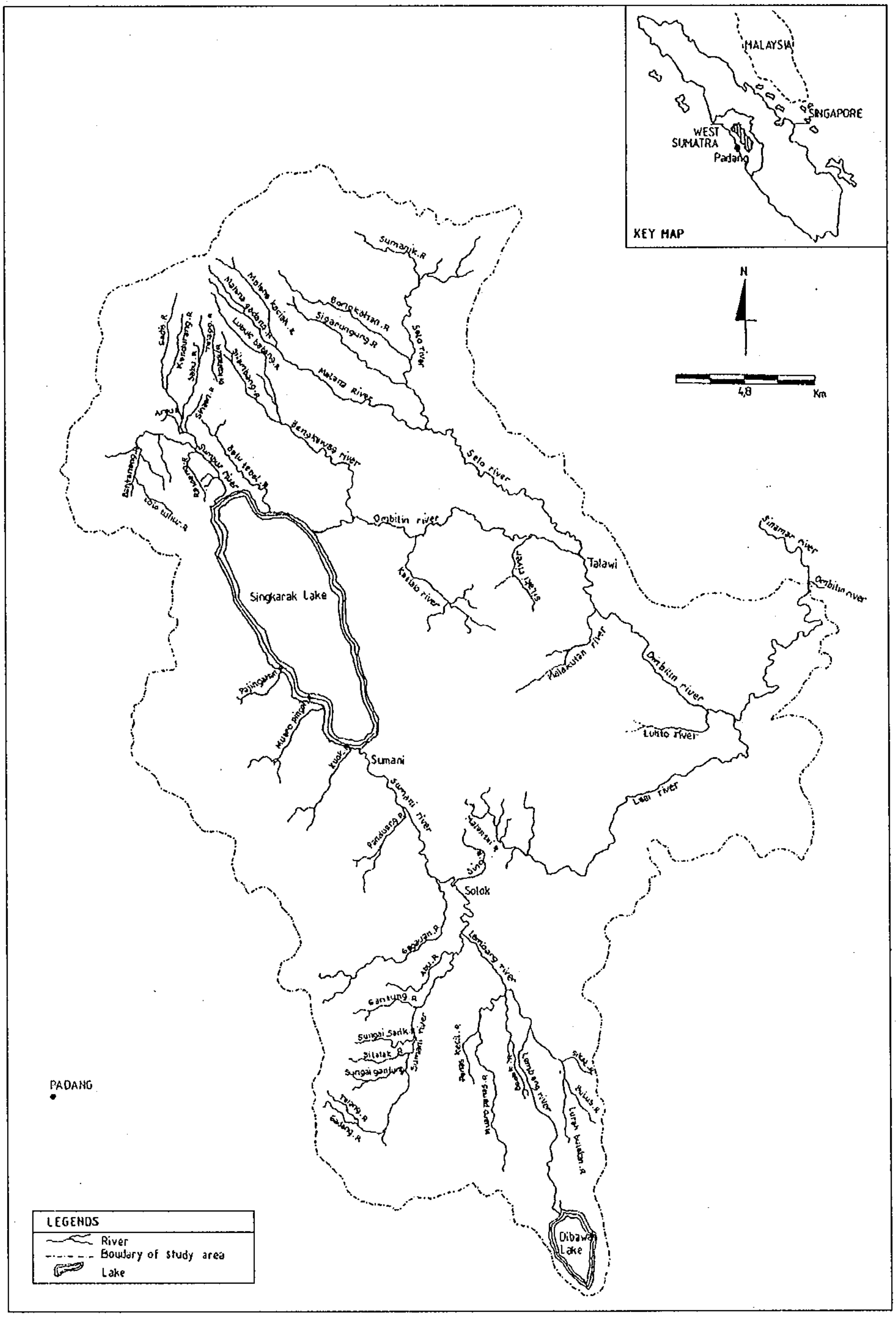
The distribution of this area within each individual basin of the rivers in the subbasin is approximately as follows: 43 percent in the Lembang/Sumani river subbasin, 14 percent in the Sumpur river subbasin, and 43 percent in the Ombilin river subbasin.

Climate and Rainfall

The basin area generally falls under the typical humid, tropic climate covering almost all of Sumatra. An agro-climatic map of West Sumatra (Oldeman et al. 1978) shows five climatic zones, composed on the basis of consecutive wet and dry months, in the basin area. Much of the subbasin areas of the Lembang/Sumani and Sumpur rivers belongs to the wettest zone, while the vast majority of the subbasin area of the Ombilin river is in the driest zone, constituting around one-third of the subbasin area. Consequently, changes in the outflows from the Singkarak lake have an important impact on water availability for the subbasin area under the Ombilin river.

Rainfall patterns in the basin area match the abovementioned agro-climatic zones. Average rainfall in the subbasin area was 2,026 mm/yr. The subbasin area of the Sumpur river is the wettest, with average rainfall of 24,843 mm/yr. This is slightly higher than the Lembang/Sumani river subbasin with an annual average of rainfall of 2,201 mm. The Ombilin river subbasin is the driest, with an annual average of rainfall of 1,789 mm.

Figure 1. Layout map of Lembang/Sumani, Sumpur and Ombilin basin.



Changes in Outflow from Singkarak Lake

In order to fulfill water requirements for power generation by the Singkarak Hydro Electric Power Plant (HEPP), the outflow from the Singkarak lake to the Ombilin river was regulated to 2–6 m^3/s. This was a significant reduction from the earlier average outflow of around 49 m^3/s. the Ombilin river (especially along the 70-km length of the river under study), water is used for irrigation, industry, electric power generation and domestic water supply. The operation of the Singkarak HEPP has affected the availability of water for various uses along the Ombilin river, which indicates the competition between the Singkarak HEPP and water users along the Ombilin river.

Water Accounting of Ombilin River

Water accounting is an art and procedure "to classify water-balance components into water-use categories that reflect the consequences of human intervention in the hydrologic cycle" (Molden 1997). Water-accounting procedures are developed based on a water-balance approach. This classification would enable the analysis of water uses, depletion and productivity in a water-basin context. There are three main components of the classification:

- inflow (which consists of gross inflow and net inflow)
- committed water (the part of outflow reserved for specific uses)
- available water is the difference between net inflow and committed water

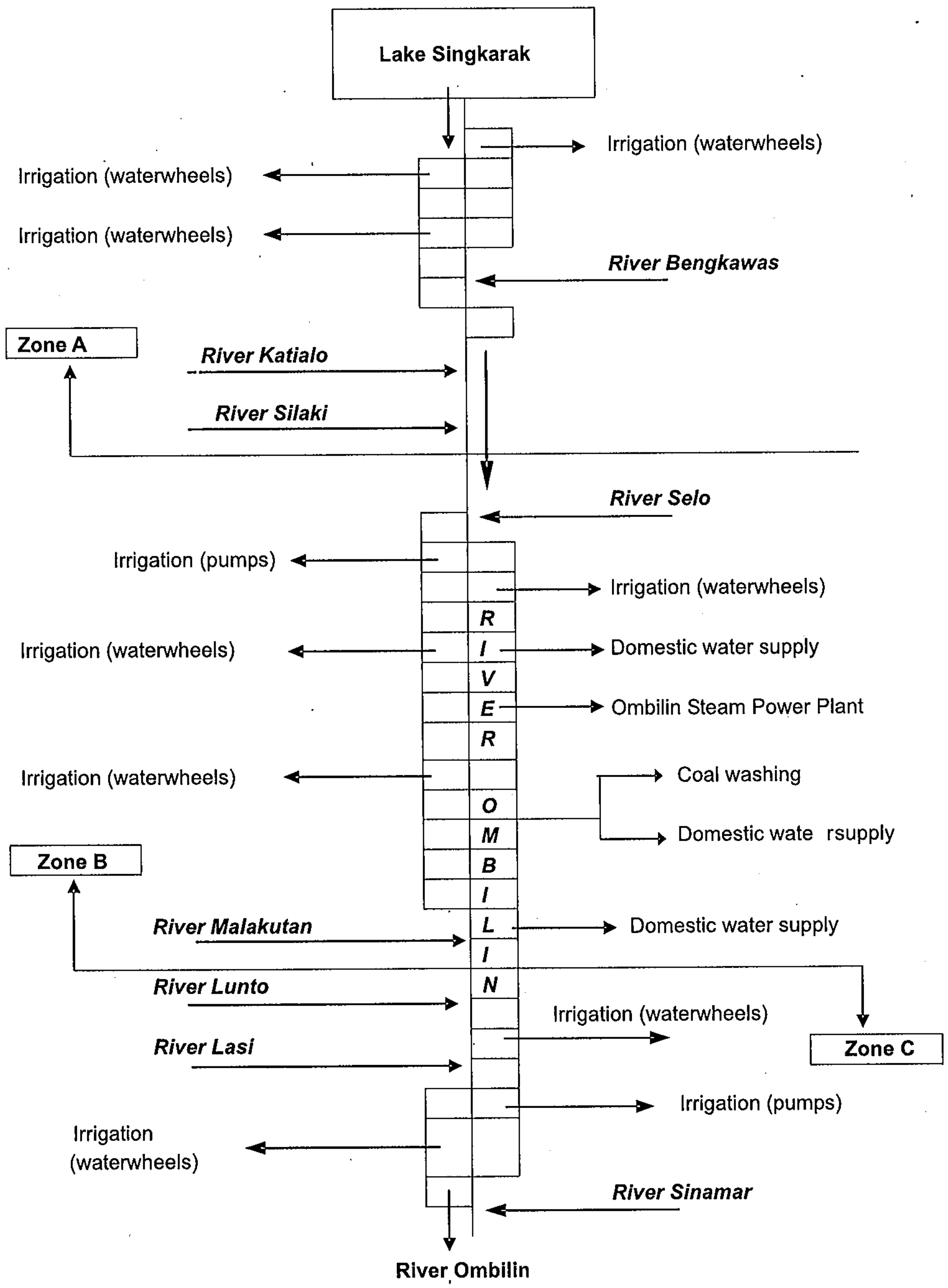
Inflows. There are seven major rivers flowing in to the Ombilin river, as shown in figure 2. Among these rivers, the Selo river has the biggest inflow into the Ombilin river, while the lowest is from the Silaki river. Figure 2 shows the activities dependent on the rivers.

Zoning of subbasin and water uses. Based on the type of water use, the Ombilin river can be divided into three zones: Zone A (upstream), Zone B (midstream) and Zone C (downstream).

Zone A is from the Singkarak outlet to the confluence with the Selo river. In this zone, the use of water is mainly for irrigation where water is lifted by using waterwheels. Three rivers flow into the Ombilin river in this zone: Bengkawas river, Katialo river, and Silaki river. The study found 58 waterwheels in this zone of which currently only 30 are still functioning.

Zone B is from the confluence of the Selo river with the Ombilin river down to the confluence with the Malakutan river,. There are three types of water use in this zone: irrigation, domestic and industrial. From the inventory, 77 waterwheels for irrigation were found, with only 38 still functional. In addition to the waterwheels, five pumping stations for irrigation are also found in this zone. For domestic and industrial purposes, there are two pumping stations for drinking water and one pumping station for coal washing.

Figure 2. Inflows, water uses and zoning of part of the Ombilin river.



Zone C includes the confluence with the Lunto river, and the confluence with the Sinamar river. In this zone, water use is mainly for irrigation by waterwheels and there are 231 waterwheels for irrigation, of which only 116 are still functioning. In addition, nine pumping stations for irrigation were found in this zone.

Water balance and water accounting. The results of water-balance computations for each zone showed that the discharge flow in each zone is still higher than the outflows or water uses for different purposes (see table 1). In Zone A, Zone B, and Zone C only about 5.4 percent, 30.6 percent, and 12.7 percent, respectively, of the water is being used. The data suggest that pressure on water resources is highest in Zone B, followed by Zone C and Zone A.

Table 1. Results of the water balance computation for the Ombilin river.

Items	Zone A		Zone B		Zone C		Water flowing downstream
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	
	m³/det	m³/det	m³/det	m³/det	m³/det	m³/det	
Singkarak lake	3.33	-					
Bengkawas river	1.19	-					
Katialo river	2.97	-					
Silaki river	0.07	-					
Irrigation	-	0.41					
Water balance	7.56	0.41	7.15				
Selo river			3.96				
Irrigation			-	0.92			
Talawi Domestic Water Supply Company			-	0.04			
PLN thermal power plant			-	0.01			
Thermal power plant			-	1.90			
Coal washing			-	0.14			
Rantih pump station (Domestic Water Supply)			-	0.40			
Water balance			11.11	3.41	7.71		
Malakutan river					1.32	-	
Lunto river					0.64	-	
Lasi river					2.02	-	
Irrigation					-	1.49	
Water balance					11.69	1.49	10.20

Water Management under Stress

There are four issues related to water management in the subbasin: a) interbasin water transfer; b) impacts of the construction of the Singkarak Hydro Electric Power Plant (HEPP) on irrigated agriculture and other users; c) lack of a framework for water rights licensing and water charges; and d) lack of an organization for river-basin management.

Interbasin Water Transfer

As mentioned earlier, the water used by the Singkarak HEPP does not return to the Ombilin river (which flows to the east coast of Sumatra). In order to gain sufficient head, the water is channeled (by a tunnel through the mountain range) to the Anai river, which flows to the west coast of Sumatra. This transfer to the Anai river reduces the availability of water for the users along the Ombilin river. The fragmentation of water-management responsibilities among a number of government agencies makes coordinated action among them a constraint. The tendency is that when any particular government agency has developed any particular water source, the control of water uses is assumed to be in that agency's hand. Other users are expected to adjust themselves to the changes in water availability.

Impacts of the Singkarak Hydroelectric Power Plant

Impacts on Irrigated Agriculture

The impacts on irrigated agriculture mainly concern waterwheel irrigation systems. Waterwheels lifted water from the Ombilin river for irrigation. Recently, diesel pumps also began to be used to lift water from the river. No surface-irrigation systems were found along the Ombilin river. Diesel pumping began to be used because of the difficulties farmers faced in operating waterwheels under low discharge flows in the Ombilin river. There are surface-irrigation systems on the tributaries of the Ombilin river, but these irrigation systems were not affected by the operation of the Singkarak HEPP.

Reduction in the number of waterwheels and irrigated area. Farmers feel that waterwheels and pumps constitute the most suitable system under the physical conditions along the Ombilin river. The limited rice fields available, their locations scattered over the narrow flat area along the river, and the average width of the river of around 50 m would make the construction of weirs for surface irrigation very costly. Furthermore, the porous soil requires continuous flows of irrigation water.

The field inventory found some 184 waterwheels serving 333 hectares and 463 farmers. On average, a waterwheel served an area of 1.8 hectares, with 2.5 farmers involved. Pump-irrigation technology has just begun to be used in the last few years. This was especially true for those whose land could no longer be served by waterwheel irrigation systems. At the time of the field inventory, 14 pump irrigation units were found along the Ombilin river, with a total command area of 138.5 hectares involving some 200 farmers.

Irrigation has been severely affected by reduced discharge in the Ombilin river. Looking at the number of waterwheels, command area, and number of farmers served during the period after the development of the Singkarak HEPP, it can be concluded that the number of waterwheels has declined markedly. The number of currently existing waterwheels is only around half of that in 1996 before the operation of the Singkarak HEPP started. Current irrigated area is approximately 61 percent of that in 1996. Table 2 below shows changes in the number of waterwheels, service area, and farmers at the Ombilin river during the last 5 years (1996–1999).

Table 2. Number of waterwheels, service area, and farmers in the Ombilin river from 1996 to 2000.

Year	Number of waterwheels	Total service area	Total number of farmers involved
1996	366	549	729
1997	296	470	621
1998	237	405	556
1999	195	343	478
2000	184	333	463

Source: Field inventory.

Increased O&M costs of waterwheel irrigation systems. For owners and operators of waterwheels, reduction in the water discharge to the Ombilin river has caused several problems in system operation and maintenance (O&M). First, the current discharge flows of the Ombilin river, especially in the dry season are, often, not sufficient to rotate the waterwheels, or only allow a very low rotation per minute (rpm). Consequently, operators have to lengthen the traditional weirs as a way of increasing water depth and directing water toward the wheel, so as to make it rotate faster. Another way of continuing the operation of waterwheels under such a condition is to reduce the number of water tubes so the waterwheel becomes lighter and easier to move. Nevertheless, the consequence of both choices is an increase in the workload and cost of O&M of the system, and a reduction in the capacity of waterwheels to supply water, which means a decrease in the area of land that can be irrigated and less reliability of irrigation water.

Increased intensity of damage to traditional weirs and waterwheels is due to drastically increased river discharges resulting from sudden opening of the gate at the Singkarak outlet. According to the farmers, the gatekeeper usually opens it during the rainy season to avoid flooding of the settlements and irrigated areas in the lowland surrounding the Singkarak lake. Consequently, the Ombilin river discharges increase during the rainy season, because of the additional inflow coming from the Singkarak lake.

For the owners and operators of waterwheel irrigation systems, increased damage means more labor and capital costs if systems are to be repaired. Results of the socioeconomic survey show that, on average, the intensity of waterwheel damage increased from once per season before the operation of the Singkarak HEPP to 2.5 times per season (table 3).

Table 3. Damage intensity, and average rehabilitation costs of waterwheels and weirs before and after development of the Singkarak HEPP.

	Before HEPP	After HEPP	% increase
Frequency of damage			
(times per season)			
Waterwheels	1	2.5	150
Weirs	1	4.5	350
Rehabilitation costs			
Waterwheels	Rp 150,000	Rp 1,100,000	633
Weirs	Rp 50,000	Rp 425,000	750

Source: Socioeconomic survey.

Unreliability of irrigation water and decline in rice yield. Higher intensity of damage to waterwheels has created problems for irrigation water supply. Most farmers reported that their irrigation water supply has been unreliable after the development of the Singkarak HEPP due to the abovementioned problems in system O&M. As a result, the growth and yield of rice on land irrigated by waterwheels declined markedly. Some farmers reported a lighter effect while some others noted a considerable decline. The socioeconomic survey showed that as a whole, yields of rice dropped from an average of 4.2 tons per hectare in the period before the development of the Singkarak HEPP to 3.1 tons per hectare in 1999.

Performance of irrigated agriculture. The performance assessment suggested that irrigated agriculture has declined during the last 5 years. Seven indicators measured performance: (1) output per unit of cultivated area; (2) output per unit of command area; (3) output per unit of irrigation water; (4) output per unit of available water; (5) relative water supply; (6) relative irrigation supply; and (7) financial self-sufficiency. Most performance indicators for waterwheel irrigation systems have declined. Relative water supply and relative irrigation supply declined sharply, which in turn brought about reductions in output. The main factor that caused the declines was the reduction in the total water supply at the field and in the irrigation supply at the field. As a result, the overall performance of irrigated agriculture declined markedly. This condition can be attributed to the lack of effective water-management institutions in the Ombilin river subbasin under conditions of growing inter-sectoral competition for water. With regard to irrigation water management, a major point is that the existing irrigation technology (particularly traditional waterwheels) is no longer suited to the recent condition of water scarcity. Opportunities remain to increase the performance of irrigated agriculture in the area of Ombilin river subbasin by establishing institutions for managing water in the basin, and by improving irrigation technology to cope with the problem of increased water scarcity.

Impacts on Industry and Domestic Water Supply

The reduction in the Ombilin river flows also affected both the water supply of the pump station for coal washing and the quality of domestic water supplies. However, the coal-washing company only experienced problems initially. The company operating the Singkarak HEPP built a weir to improve the water level, which solved that problem.

The decline in the water quality in the Ombilin river brought about some problems for the domestic water suppliers and consumers. The pollution comes from the Selo river, which transported sediment especially during the rainy season, and from coal washing. Water quality in the downstream portion of the Ombilin river declined after the operation of the Singkarak HEPP began. This is shown by an increase in electric conductivity. When records in 1994 and 2000 are compared, it is seen that soluble solid material has risen from 104 mg per liter to 176 mg per liter, pH from 7.2 to 8.4, nitrate content from 0.26 mg per liter to 0.35 mg per liter, chloride from 4.62 mg per liter to 8.4 mg per liter, and sulfate from not detected to 10.3 mg per liter.

The decline in water quality increased O&M costs of the domestic water suppliers. The manager of a water company estimated that water treatment cost increased by almost 100 percent. However, at the time when raw water quality is very low, the domestic water suppliers do not perform water treatment since it would not yield any improvement in the quality of water. Under such conditions, the domestic water company distributes raw water directly to the customers without treating it.

Frameworks for Water-Rights Licensing and Water Charges

According to national laws and regulations, water rights are to be given in the form of use rights and allocated by the government through the mechanism of licensing. Since water and source of water are considered to embody social functions, there are uses of water that require licenses, and others that do not. Tapping water for noncommercial drinking water and other individual domestic uses is allowed without a license as long as it does not harm the source of water and other water users' interests. According to Ministerial Regulation No. 48/PRT/1990, a government license is required for uses such as domestic water supply, municipality and real estate, irrigation, animal husbandry, plantation, fishery, industry, mining, energy, navigation and waste disposal.

The Minister of Public Works and the provincial governors are authorized to issue licenses for water use rights within basins under their authority. Licenses for groundwater use are to be issued by the Minister of Mines and Energy. Licenses for water use may be given to individuals or groups of individuals or any legal entity. A group holding a license to use water is authorized to arrange water distribution among its members based on government regulations. Those granted licenses must pay fees to the ministry or to the governor. According to Ministerial Regulation No. 48/PRT/1990, the fee is to be used for financing O&M of water structures and maintaining the sustainability of water sources. Every license for water use has a limited duration depending on the kind of use. The fee is supposed to be set every 5 years.

Article 18 of Ministerial Regulation 48/PRT/1990 states that giving up a water license or selling it to other parties may be allowed if the issuing agency license gives its permission. However, the regulation is not explicit on how this would occur. Formal water use rights and allocation are hardly implemented, except to a limited extent in two basins on Java managed by publicly owned companies. Problems concern not just gaps and inconsistencies in the formal regulations, policies and organizations. A lack of consensus on some key concepts (Pusposutardjo 1996) and the lack of hydrological data in most of the basins (Hehanusa et al. 1993) make it impossible for the government to make basin-level planning or even to make the right decisions on whether or not new uses of river water are justifiable.

Regulations stipulate that licenses for water uses, which potentially affect water balances, must be based on general basin-level plans on development, protection and utilization of the basin water. In cases where such plans have not been made, the issuance of the licenses must be based on consensus made in the coordinating body, the Provincial Water Management Committee. However, it is not clear what the basis for such a consensus would be.

In practice, for most basins, water allocation is governed by whatever local communities accept as rules. In predominantly agricultural basins, *adats* (traditional customary rights) may govern water allocation. For the Ombilin river, there were no local rules for water allocation since the challenge was lifting water from the river. In the context of waterwheel irrigation, the results of water accounting showed that, in aggregate, the water supply is sufficient but the problem is the water level required to operate the waterwheels.

Where nonagricultural sectors have exerted their interests, claims over water may be based on political or economic power leading to transfer of water from the agriculture sector (Bruns et al. 1996). Nevertheless, government wields, and is capable of exercising, the authority in water allocation, including interbasin water transfers. Transferring water from the Ombilin river to the Anai-Sialang basin is an example. Apparently, the decisions on this transfer were made on the basis of studies done by the government. The original water users must adjust to the new situation. One of the impacts of the government action on farmers along the Ombilin river is that it has affected the operation of their waterwheels in supplying water to their paddy fields due to lower river flows. Moreover, the lower flow has also made domestic pollution more felt in the downstream areas of the Ombilin river. This underlines the importance of formalization of irrigation water rights in order to protect the interest of the poor and small farmers.

Absence of an Organization for River-Basin Management

As mentioned earlier, the incorporation of the idea of river-basin management into policy and action is relatively new to Indonesia. Furthermore, the management framework is not yet developed except in two basins on Java Island that are managed by publicly owned corporations. These are the Brantas river basin in East Java under the management of Jasa Tirta Public Corporation One, and the Citarum river basin in West Java under Jasa Tirta Public Corporation Two (formerly called the Jatiluhur Authority).

In other provinces of Indonesia, the idea of river-basin management has been newly introduced. As the responsibility for water management is fragmented between several government agencies, a provincial water management committee (in Indonesian language abbreviated as PTPA) is supposed to be set up in each province. In West Sumatra the PTPA was set up in 1994. The characteristics of this committee are as follows:

- Its main function is to assist the governor in coordinating water management at the provincial level.
- Its specific tasks are a) data collection, processing and preparation of materials to be used to formulate provincial policy on water-management coordination, and b) to provide considerations and/or advice to the governor on matters related to water supply, wastewater drainage and flood control.
- The members of the committee are the staff from agencies related to water management (other stakeholders were not included as the members of the committee).

There was no specific budget allocated for this committee, so its activity was on an ad hoc basis. When there were problems related to water supply, drainage or flood, a meeting of provincial staff would be held, but it was not very clear whether the meeting was a PTPA meeting or just a meeting related to the performance of general government tasks.

The government regulation related to the provincial PTPA also had articles stating that the governor could set up basin-level water-management committees (PPTPA) to assist the PTPA in performing its tasks. However, up until now such a committee has not been set up in any of the six river basins located in the West Sumatra Province. As the conflicts over water allocation and use increase in West Sumatra, as illustrated with the case of the Ombilin river, clearly, there is a need to develop a framework for improvement of river-basin management in the province. The case of the Ombilin river can be used as the pilot activity to develop the framework and capacity for integrated water resources management (IWRM) at the basin level in West Sumatra.

Toward Effective Institutions for IWRM in a River-Basin Context

Agenda for West Sumatra

The preceding sections showed the need to develop effective water management institutions. Based on study activities, an agenda for improving water management in the upper subbasin of the Inderagiri river basin (especially in the Ombilin river subbasin) is discussed below.

The first, short-term agenda would deal with the impacts of operation of the Singkarak HEPP on the downstream users. The options that can be considered are as follows.

In the short term, especially during the dry season, the problems faced by the users need to be solved by reviewing the existing water-allocation rules and releasing more water from the Singkarak lake to the Ombilin river. For this purpose, the handling of water-allocation matters needs to be done systematically. The affected users along the Ombilin river have proposed that a kind of water board, which would consist of all of the stakeholders, be set up and given authority to regulate water allocation from the Singkarak lake.

The technology for lifting water for irrigation, both with waterwheels and diesel pumps, needs to be adjusted given the changes in the water level at the Ombilin river and the cost of operation of the pumps. The soil porosity is high, so a 24-hour water supply is needed.

Waterwheels are very well suited for this environment, but the water level in the river is no longer sufficient to continue operating efficiently with the current technology. With regard to the pumps, the farmers indicated that they have difficulties with the cost of pump O&M and are thinking about using electric pumps for lifting water from the river. Farmers proposed that the electricity company provide a special discount for electricity to the domestic water-supply company and the farmers who use electric pumps for irrigation, as a "good neighbor policy."

Second, for the long term, the government needs to set up a coordinating committee (PPTPA or a kind of water-management committee) at the subbasin level. The main task of this body would be to regulate and enforce the water-allocation rules effectively, in accordance with the basis provided by the national water-resources policy. The long-term action plan to improve water management would consist of several activities.

All the water-related laws and regulations at the provincial level should be reviewed and adjusted in accordance with the direction of the new national water policy. This would include laws and regulations related to water rights; strengthening the water resources management coordinating committee at provincial level (PTPA); establishing water-resources management coordinating committees at basin and subbasin levels; and reviewing the possibility of charging a tax for using surface water, and using the income generated from this to finance the operation of the coordinating bodies, and for river and watershed maintenance. In the preparation for setting up coordinating and/or operating bodies for the management of other rivers (subbasins) the officials concerned could benefit from using the Ombilin river subbasin as a pilot site.

National Policies

The Government of Indonesia is currently reforming its water resources and irrigation management policy. The reforms have four objectives (BAPPENAS 2000):

1. Improving the national institutional framework for water resources development and management.
2. Improving the organizational and financial framework for river-basin management.
3. Improving regional water-quality management regulatory institutions and implementation.
4. Improving irrigation management policy, institutions and regulations.

Among these objectives, the first and second are closely related to the improvement of water allocation from the source and river-basin management. One of the five sub-objectives of the first objective clearly mentions the involvement of stakeholders (including the private sector) in river-basin management and decision making. The proposed reforms in this sub-objective cover three areas, namely:

- Issuing a government regulation that puts emphasis on the participation of stakeholders (public agency institutions, community and private sector) in water-resources development and management.

- Amending the ministerial regulation to i) include stakeholder representatives in provincial- and basin-level water-management coordination committees, and ii) merging provincial water-management committees with provincial irrigation committees.

- Establishing functional, provincial- and basin-level water-management committees with stakeholder representation in key river basins in 12 provinces.

The second objective contains three sub-objectives, one of which is the improvement of provincial regulatory frameworks for river-basin and aquifer management. This will be a basis for the development of effective water-management institutions at the provincial and basin level.

Progress Achieved in West Sumatra

Improvement of water management in West Sumatra requires continuous and consistent efforts to lay down necessary foundations. The Provincial Water Resources Management Agency has started taking initiatives. The agency has held a series of stakeholder dialogues in order to prepare a draft provincial water regulation. This regulation attempts to address the problems and challenges of water management by referring to the national water-policy reforms and the principles and frameworks for IWRM. Approval has been given to set up technical implementation units for river-basin management (as a preliminary body or embryo for River Basin Organizations). Better water management would also require improvement of provincial water-resources information and decision-support systems.

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Development of Effective Water-Management Institutions: The Case of the Upper Pampanga River Basin, Philippines

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Introduction

The Upper Pampanga River Basin (UPRB) is one of the biggest river basins in the Philippines and is located in Central Luzon, Philippines (figure 1). The estimated total area is 420,000 hectares, covering several cities, and 25 municipalities in the provinces of Nueva Ecija, Pampanga and Bulacan. Nueva Ecija occupies the biggest portion of the river basin.

The basin provides abundant water resources for a large population, growing industries, and agricultural production in a vast fertile rice land in the Central Luzon region. While the current water resources are still abundant, there is concern whether they will be able sustain the water requirements of the growing population. There is an urgent need to protect and manage the basin for the future generation. This is an enormous task, and the absence of a coordinating body to effect an overall water management necessitates the creation of the UPRB coordinating council.

This paper highlights the resources within the UPRB and the reforms needed to effectively manage the river basin. The next section profiles physical systems, socioeconomic conditions and stakeholders in the basin. The subsequent sections discuss the major water-management issues, institutional reforms and future plans. The creation of the Upper Pampanga River Basin Coordinating Council (UPRBCC) is the focal point of this paper. It is envisioned that the council could be an effective institution to develop and sustain the water resources of the basin.

Profile of the Basin

Physical System and Water Resources

The UPRB has two distinct seasons. The wet season is from May to November and the dry season from December to April. The average rainfall is 1,900 mm for a normal year and 1,100 mm for a dry year. Rainfall during the rainy season is brought about by the southwest monsoon, accompanied by an average of 22 tropical depressions during this part of the year.

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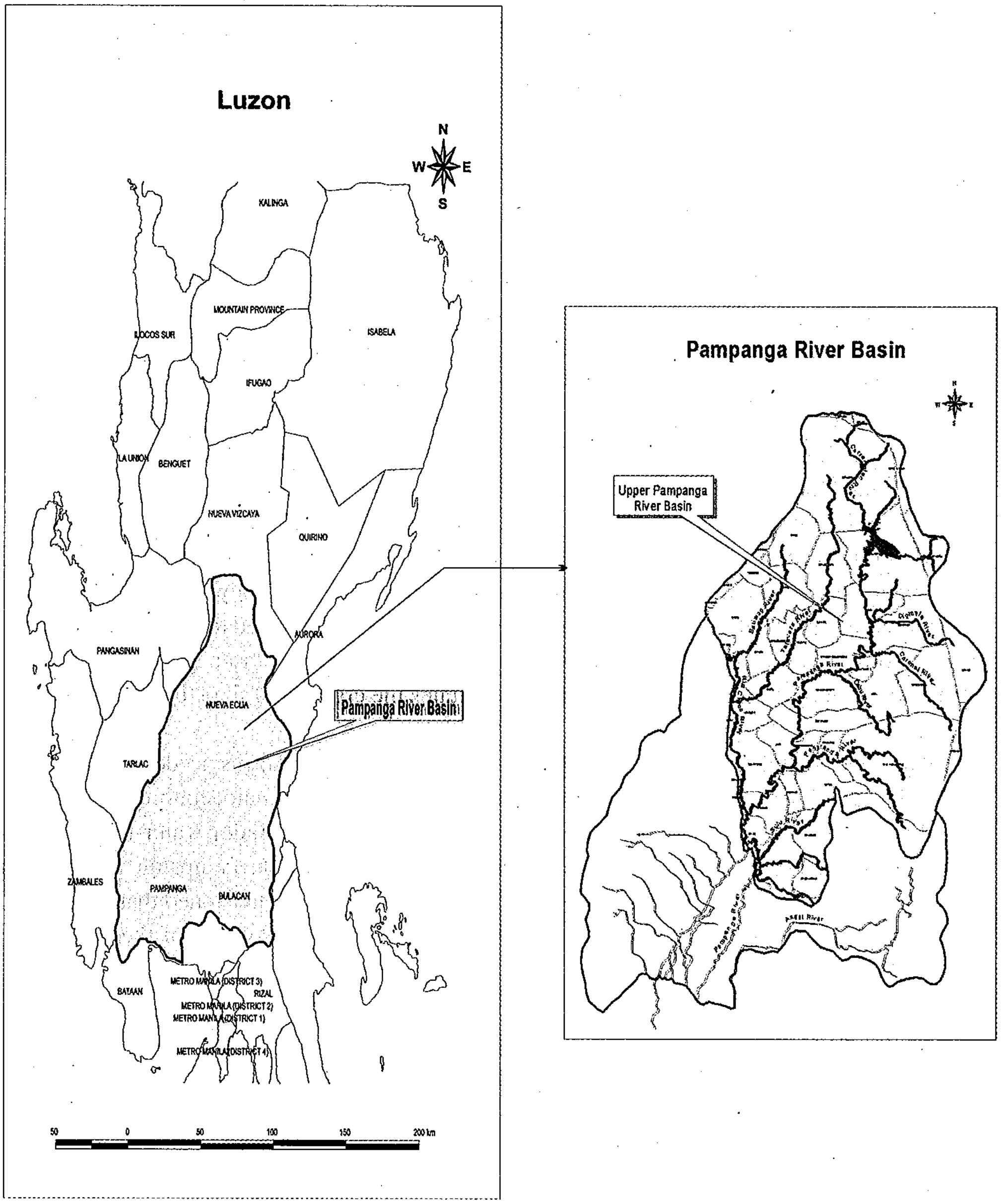
Figure 1. Location of the Upper Pampanga River Basin.



The physical system of the basin consists of the Pantabangan reservoir, river system, diversion dams, and irrigation channel networks that supply water for irrigation and fisheries, and for municipal, industrial and other requirements. The major river tributaries are the Awilan, Digmala, and Coronel rivers in the upper reaches of the Pampanga river and the Talavera and Peñaranda rivers, as shown in figure 2. Within the UPRB is the Upper Pampanga River Integrated Irrigation System (UPRIIS), which became fully operational in 1975, mainly for irrigation. UPRIIS is one of the biggest national irrigation systems in the Philippines. Its total service area is 102,532 hectares, about 24 percent of the whole basin, as shown in figure 3. Communal irrigation systems (CIS) provide irrigation to about 2,500 hectares of rice and diversified croplands. Individually operated 4-inch shallow well pumps also contribute to the overall irrigated areas in the UPRB. As many as 1,571 units of shallow well pumps and engine sets with an average discharge of 9 liters per second (lps) were installed from 1997 to 1998; each one capable of irrigating 10–20 hectares. Additional physical infrastructure is being constructed by the Casecnan Multipurpose Irrigation and Power Project (CMIPP). This project is expected to irrigate 35,000 hectares of agricultural land and provide hydroelectric power of 150 MW. The irrigation component of the project consists of 64 km of a super diversion canal and 611 km of laterals and sub-laterals, together with water-control structures and irrigation facilities

Water in the basin is also utilized for hydropower, a plant that produces 150 MW of electricity, and is reused for irrigation. The basic profile of the basin is shown in table 1.

Socioeconomic Conditions

The UPRB is relatively large in terms of population, land area and coverage. In 1995, the population with the basin's administrative boundary was 1.58 million. The population growth rate is 2.86 percent per year, which is very high by international standards and higher than the country's (2.3) and the region's (2.12) growth rates. Population in the basin is projected to reach 2.1 million in 2005. Population density was 341/ha in 1995, an increase of 45 persons/ km^2 in a span of 5 years. The proportion of the population highly dependent on the household for survival (0 to 19-year-olds and over-65-year-olds) is relatively large at 50 percent. Urban population was 36 percent in 1990, 13 percent higher than the 1980 level, and it is expected to increase because of the growing importance of the nonagriculture sector and migration in the domestic economy.

The river basin is primarily agricultural. Figure 4 shows the land cover in the basin. Agriculture is the major source of employment and income, particularly in Nueva Ecija which is considered to be the major rice-producing province in the country. The labor force in agriculture in Nueva Ecija is 57 percent while that in Bulacan and Pampanga it is 30 percent in each. Farming households constitute about 50 percent of the total households. In addition to crop production, poultry, livestock and pigs are raised. Light industries such as feed mills, rice mills, ice plants, and cold storage for onions contribute to the basin's economy. Commercial establishments abound in population centers within the basin, especially in first-class municipalities like Santa Rosa, Gapan and San Miguel, and in cities like Cabanatuan and San Jose. However, commercialization of agricultural and nonagricultural activities in the basin has given rise to environmental pollution.

Figure 2. Rivers in the UPRB.

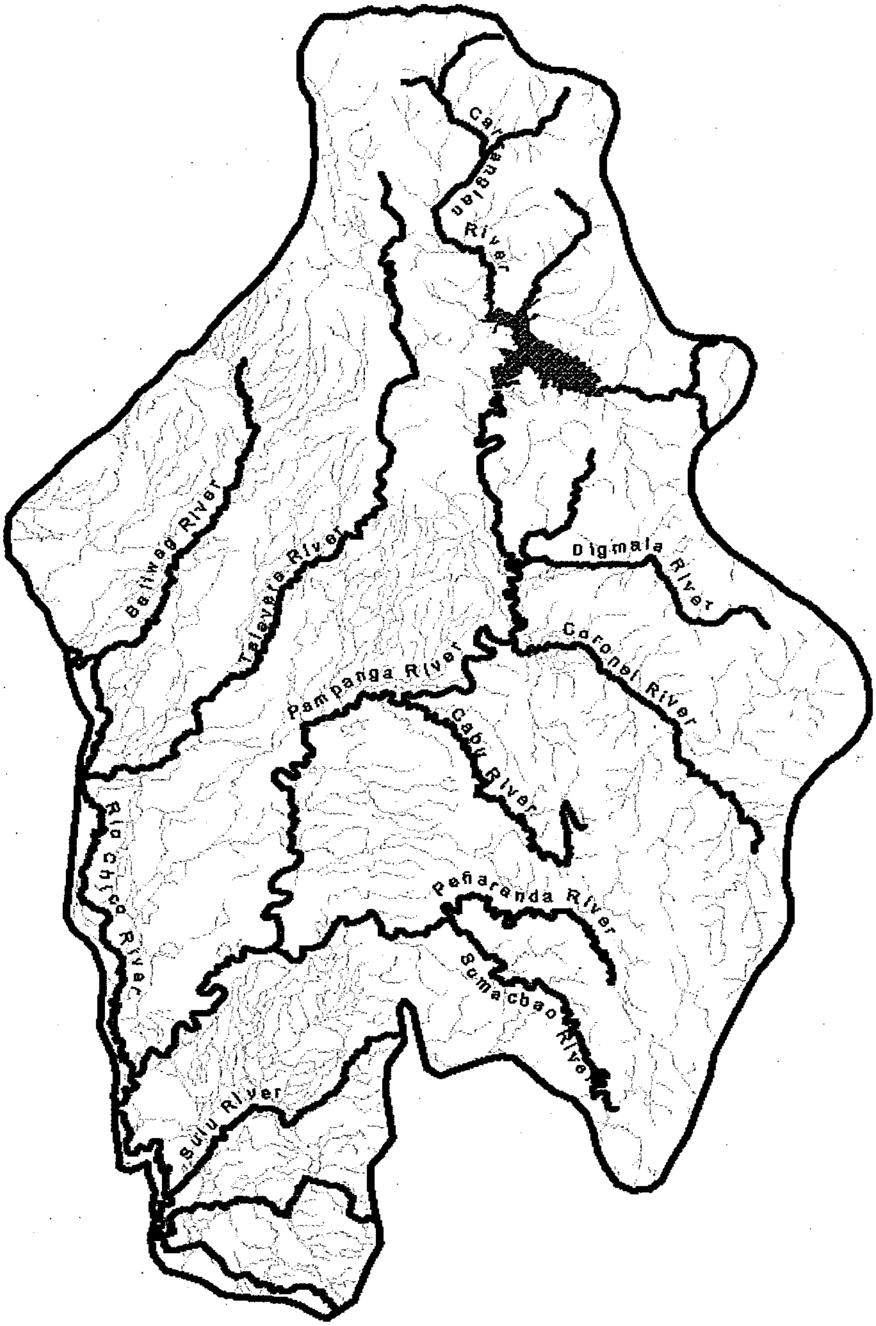


Figure 3. UPRIIS districts and communal irrigation systems within the UPRB.

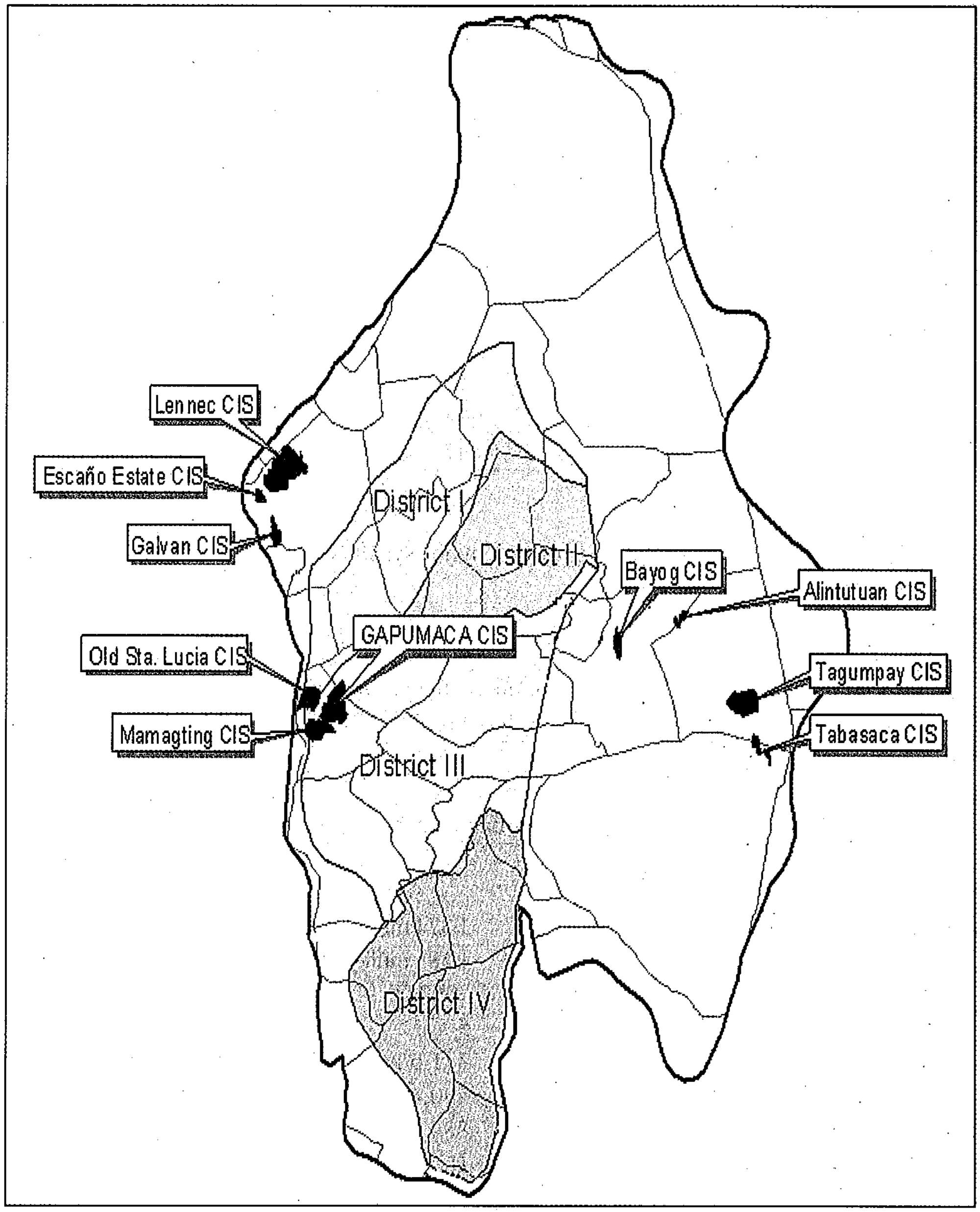


Table 1. Basic profile of the UPRB.

1. Basin Characteristics				
General Information				
Geographical area	4,200 km²			
Location	N14° 45' to N16° 10'; E 120° 20' to E 121°15'			
Physiographic features	Plains 90%; Mountainous 10%			
Average rainfall				
Normal year	1,900 mm			
Dry year	1,100 mm			
Agro-climatic information (average for 1989–1999)				
Location	Total rainfall	Total evaporation	Average temperature (°C)	Average humidity (%)
Central Luzon State University	1,994	1,904	28	75
Cabanatuan City	1,754	1,847	28	81

2. Facilities/Assets	
No. of irrigation schemes (surface irrigation)	4 major systems
No. of hydropower plants	1
No. of rainfall stations	2
No. of pan evaporation stations	2
Large reservoir	1 (2,996 million m^3)—Irrigation, hydropower, industry
Shallow wells	1,571—Deep wells 11

3. Urban Centers			
No. of urban centers	4	Area of urban centers	807 km²

4. Socioeconomic Data		
Total population	1.374 million	(1990)
	1.583 million	(1995)
No. of households	308,347	(1995)
Average household size	5	
Population density	341 p/km	(1995)
Maximum population in the urban sector	490,425	(1990)
Maximum population in the rural sector	884,470	(1990)
Ratio of urban: rural population	1:1.8	
Per capita land area	0.006 km²	(1995)
Households with piped water	28% of total	
Number of IAs (under NIS)	365	
Number of IA members (under NIS)	61,880	

5. Land Use and Agriculture

Cultivated area	254,490 ha
Urban land area	67,365 ha
Irrigated area	200,987 ha
Average Landholdings	1.4 ha–3.0 ha
Major farm crops	rice, onion, garlic, vegetables
Cropping intensity	120% (1998)
	154% (1999)

Sources: NCSO 1990, 1995; PAGASA 1990–1999; BAS 1999.

In Nueva Ecija, the average farm size has continued to decrease from 3.47 hectares in 1971 to 1.78 hectares in 1991. Similar trends were reported in Pampanga and Bulacan due to fragmentation and land conversion. If these activities continue, food supply in the basin will be a problem unless efforts are made to increase productivity per unit area.

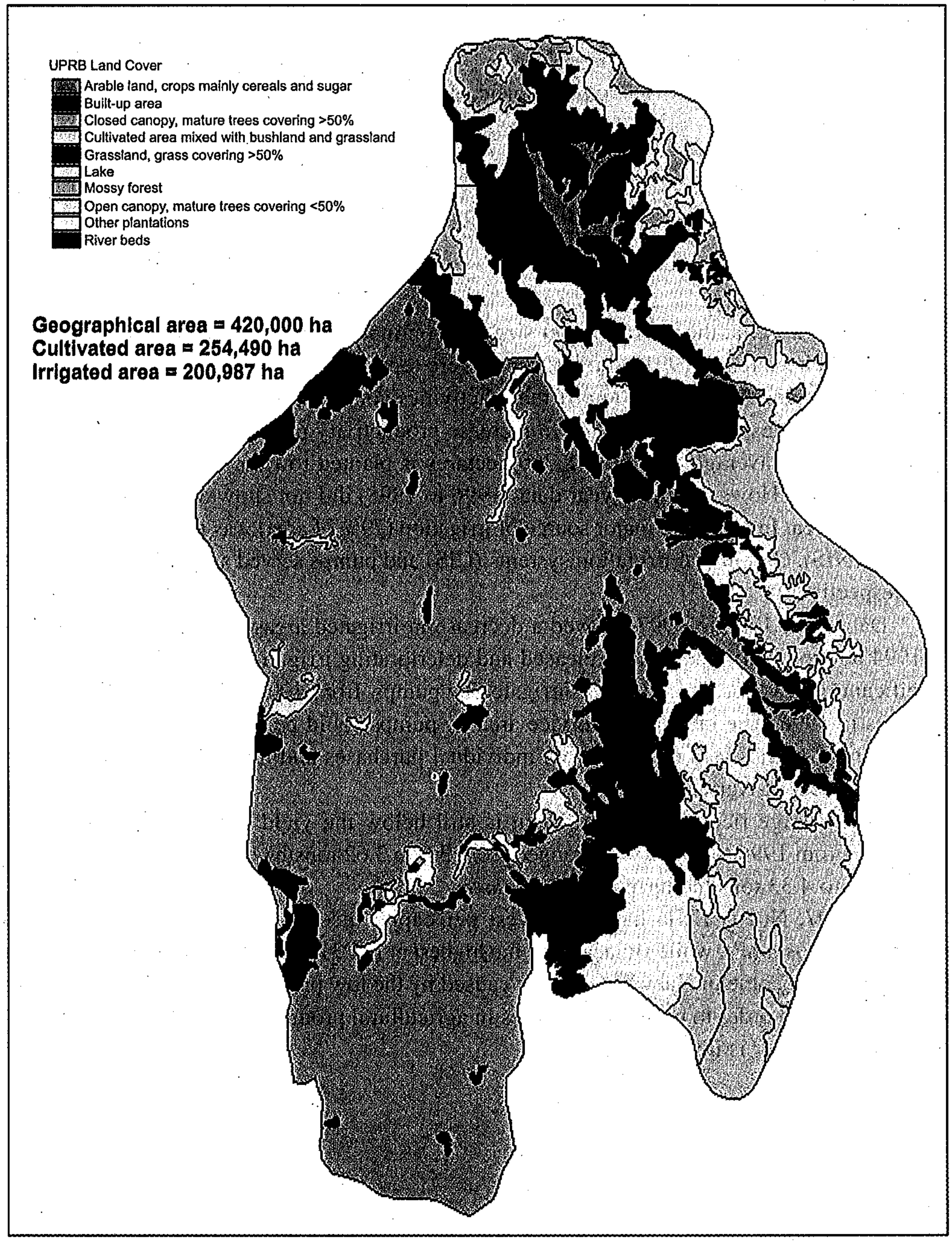
An annual average area of 218,710 hectares is planted to rice, 92 percent of which is irrigated paddy. However, the 3-year data (1996 to 1998) did not show a significant increase in irrigated area. In 1997, the major source of irrigation (79% of area) was the national irrigation systems (NIS). Communal irrigation systems (CIS) and pumps served smaller areas (12% and 9%, respectively).

Data from 1992 to 1997 showed a decrease in irrigated areas by NIS in 1993 and CIS in 1994 due to insufficient water released and deteriorating irrigation facilities. In contrast, a significant increase occurred in areas irrigated by pumps, from 400 hectares in 1992 to 10,000 hectares in 1996. The increase in service area by pumps could be attributed to an increase in ownership of pumps as a result of both individual purchases and the distribution program of the Department of Agriculture.

The average rice yield in the basin is still below the yield potential of modern rice varieties. From 1996 to 1999, yield ranged from 3.0 to 3.62 tons/ha during the wet season and from 3.73 to 4.33 tons/ha during the dry season.

In 1997, Nueva Ecija had the lowest per capita income of PhP 20, 959 (US$1=40 Philippine pesos, PhP), while Bulacan had the highest at PhP31,343. The low household income and per capita income in Nueva Ecija were caused by the low productivity and low farm prices in agriculture. In order to promote increases in agricultural productivity, efficient use of labor, fertilizer and water is important.

Figure 4. UPRB land-cover map.



Stakeholders in UPRB

Considering that agriculture is the primary source of employment and income within the UPRB, the National Irrigation Administration-Upper Pampanga River Integrated Irrigation System (NIA-UPRIIS) and its thousands of farmer beneficiaries who are mostly members of the irrigators associations (IAs) are considered the major stakeholders of water from the UPRB. As of December 31, 1999, altogether 365 IAs in the whole of NIA-UPRIIS had been recorded, with a membership of 61,880.

Most of these IAs are registered with the Securities and Exchange Commission (SEC) and currently hold contracts with NIA. They share in the management of operation and maintenance (O&M) of the irrigation systems. O&M contracts are of three types. Type I involves a canal maintenance contract. For this, an IA receives an incentive of PhP 400 for every kilometer or a total of PhP 1,400/month for a 3.5-km earth canal or a 7- km lined canal. In Type II contracts, the IA participates in system operation, and in the campaign and collection of the irrigation service fee (ISF) within its area of jurisdiction. An IA receives an incentive, based on the collection efficiency. Type III involves the transfer of O&M of a system, or part thereof, to the IA, which amortizes the direct chargeable investment cost to NIA without interest for a period not to exceed 50 years.

The objective of "shared management or participatory irrigation management" is to encourage active involvement of the associations in the O&M of the NIS. However, results of a recently concluded study that reviewed the cost-recovery mechanism for the NIS, including the NIA-UPRIIS revealed that "the NIA-IA partnership in practice is asymmetrical and that NIA controls the technical expertise and subsidizes maintenance and improvements in the canals that are being operated and maintained by the farmers (Shepley et al. 2000). In other words, the "paid" maintenance and ISF collection contracts do not provide enough accountability and incentives to the IA, and inhibit the farmers' capability for sustained O&M of the irrigation system.

Several government agencies are tasked with the administration of water in the basin. Their interests and functions are administrative and regulatory in nature. These agencies are the National Power Corporation (NPC), Department of Environment and Natural Resources (DENR), Bureau of Soil and Water Management (BSWM), Philippine Atmospheric Geophysical, Astronomical Service Administration (PAGASA), Local Water Utilities Administration (LWUA), National Electrification Administration (NEA), Bureau of Fisheries and Aquatic Resources (BFAR), and Department of Public Works and Highways (DPWH). Despite the presence of these agencies within the basin, it is still beset with problems and issues such as siltation of waterways, land conversion, water pollution, and lack of a coordinating body to promote effective water-resources management in the basin.

Major Issues Related to Water Management

The study identified five major issues related to water management in the basin, and formulated recommendations for action to address these issues.

1. Water in the UPRB, particularly within the NIA-UPRIIS service areas, has been found to be closely tied to agriculture, high population-growth rates, population density, and an increasing rate of urbanization. This close linkage has raised the need for cooperation among the various agencies and interest groups within the basin. A multi-sectoral committee or core group should be formed, composed of representatives from the NIA, DENR, local government units (LGU), the NPC, local water districts, local communities, and other interest groups. This group will be responsible for reviewing and integrating plans and projects or in developing an institutional framework that will define how the various stakeholders of the UPRB can collaborate and operate in an integrated manner. This integration is imperative because, at present, there is an apparent lack of effective mechanisms for coordination among agencies within the basin that are concerned with water management.

2. Water accounting is crucial for planning and managing water resources. However, it is extremely difficult to do water accounting within the UPRB because of the lack of trained personnel responsible for obtaining the needed information. This is aggravated by inadequate or nonfunctional staff gauges and other measuring devices in strategic locations within the basin.

3. Within the UPRB, the problem of deteriorating water quality arises due to increases in population and urban activities. Household wastes, as well as wastes of micro-industries, especially in more urbanized areas in the basin, have started to create problems. Solid wastes are being thrown in irrigation canals, disregarding municipal ordinances intended to control the degradation of surface-water quality. If these municipal ordinances and other rules and regulations for the protection of water quality are not strictly enforced, water pollution within the UPRB will become an increasingly severe problem in the future.

4. Micro-level analysis of the crop production in the UPRB shows that the predominant cropping pattern is rice-rice. This cropping pattern requires a large volume of irrigation water that is drawn heavily from the main canal of the NIA-UPRIIS. Rice fields are flooded with water, starting from land preparation until 2 weeks before harvesting.

Efforts have been exerted to teach farmers water management in rice culture for minimizing waste of water. In the past, training on rice production and proper water management at the farm level was conducted by NIA and other government and nongovernment agencies. However, farmers continued their conventional practices, indicating that the training had been unsuccessful in attaining the objective of increased water efficiency at the farm level.

5. Traditionally, NIA has been tasked with irrigation development in the country. Over the years however, amendments in the original charter of NIA have been made, primarily by virtue of Presidential Directive (PD) No. 552 issued in 1974. The PD later paved the way for NIA to implement the shared management or participatory approach for irrigation management of O&M in the irrigation system. In the NIA-UPRIIS service areas, the first IA was organized in 1975. It was only in the mid-80s that the proliferation of IAs began. Through the years, the IA proved to be potent partners of the NIA-UPRIIS as they performed their roles and responsibilities pursuant to their O&M contracts with NIA. Of late, however, the functionality of the IA within the NIA-UPRIIS has shown a downward trend, as shown in the results of the functionality survey conducted during the last 4 years. Nonfunctional IAs increased from 57 percent to 84 percent in 1999.

NIA has indicated a willingness to consider transferring to the IA full or partial authority and responsibility for operating and managing the NIS in the service areas smaller than 3,000 hectares. This impending transfer necessitates that IA's management capability be enhanced to prepare them for the responsibility of operating and maintaining the irrigation system.

Institutional Reform

The problems identified and vital issues highlighted above relating to the physical facilities, water accounting, socioeconomic condition, and system performance within the UPRB were the basis for the institutional reforms that the research team is pursuing:

1. Institutional collaboration for effective water management.
2. Strengthening and enhancing the IA's capability for irrigation system O&M.
3. Adoption of operational mechanisms for water accounting and valuation.
4. Advocacy for use of proper water-management technologies.
5. Strict enforcement of existing policies and regulations to protect water quality.

Several actions have been undertaken to support the establishment and operationalization of the Upper Pampanga River Basin Coordinating Council (UPRBCC), as described below.

Consultative meeting. A consultative meeting was held at Central Luzon State University, on November 27, 2001 attended by 22 representatives of the various stakeholders who were initially identified to constitute the UPRBCC. The Provincial Governor of Nueva Ecija chairs the council, since Nueva Ecija constitutes the biggest portion of the basin. The terms of reference or the roles and responsibilities of each of the stakeholders were identified and included as an integral part of a concept paper.

Declaration of commitment. A Declaration of Commitment was signed by the initial members of the Council at the Office of the Provincial Governor of Nueva Ecija on January 18, 2002. This activity signaled the formal operationalization of the UPRBCC.

Organizational meetings. To date, two organizational meetings were conducted, the first on April 2 and the second on May 7, 2002. The organizational structure of the council was finalized as shown in figure 5. Development plans of each of the various stakeholders were presented in order to identify activities to be undertaken by the council. Among the priority activities initially identified by the council are:

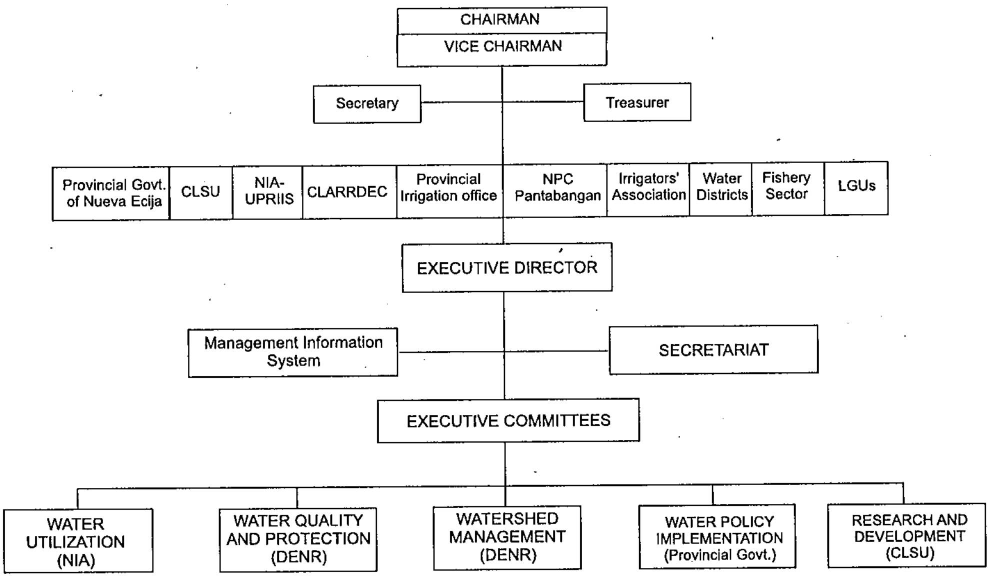
1. Advocating effective and efficient water management
2. Supporting the anti-water-pollution campaign of the local government units
3. Developing a UPRB database
4. Watershed management
5. Monitoring water quality
6. Strengthening IAs
7. Research and development

Strengthening the IA and NIA capabilities for O&M. A benchmark survey on selected Banaag ng Pag-asa IA officials and members was conducted to obtain information that could serve as the basis for strengthening the association. The information obtained from this survey was over and above that gathered during the initial phase of the project.

Among the salient initial findings are the following:

- Only 15 percent of the respondents claimed that regular meetings of the IA are held once every season (wet/dry). Such meetings are usually attended by the IA officials and some NIA-UPRIIS field personnel.
- Matters discussed during the IA's most recent meeting dealt with the irrigation management transfer (IMT), schedule of water release from the Pantabangan dam, and ISF collection.
- Most of the respondents have not attended any general assembly meeting; nor have they attended meetings of their Turn-Out Service Group (TSAG). The most notable reasons they mentioned were a) inaccessibility of the venue of the meeting, and b) lack of interest, as they believe that no tangible output would be achieved.
- Most farmers were unaware that the IA exists. They also do not know their officials, for no formal election had been held in the past several years. The present set of officials had been holding on to their positions for many years now.

Figure 5. UPRBCC organizational structure.



- Very few farmer-respondents (21%) disclosed that they had paid their ISF for the last wet season. Low yield and income were cited as the major reasons for non-payment of their ISF accounts.
- Most farmers signified their willingness to pay the ISF, provided that the main and lateral canals are rehabilitated and farm-to-market roads are constructed.

Inspection of infrastructure. A visual inspection of irrigation facilities within the area was conducted on September 27, 2001 to provide a more in-depth evaluation of the physical facilities. Results showed poor maintenance of irrigation facilities. The flow of water is obstructed by the presence of weeds, trees and debris along the lateral.

Meetings with the IA officials and members. In its desire to strengthen the capability of the IA officials and members, the research team conducted several meetings with the Banaag ng Pag-asa IA Board of Directors (BOD) and different TSAG chairmen and members. Two BOD meetings were conducted on August 28 and November 28, 2001. Some of the salient matters discussed during the meetings were:

- Orientation of the board about NIA's IMT program and the CLSU-NIA-IWMI-funded research project.
- New elections for President, Vice President and Treasurer.

- The problem regarding the poor condition of the farm-to-market road was presented and discussed. A resolution was prepared requesting the Provincial Government to help in the repair/construction of this farm-to-market road. The resolution was favorably acted upon by the Governor and the Provincial Engineer, through the endorsement of the research team.

Meetings with TSAGS. As of February 27, 2002, separate meetings with ten TSAGs had already been held by the research team. Table 2 shows some of the details of the meetings with the different TSAGs. A general assembly/meeting was set for May 22–23, 2002.

Other activities. Field visits involving the BOD/TSAG officials were carried out on December 13, 2001 to expose the farmers to the different income-generating projects of the CLSU.

National Workshop. On April 16–17, a national workshop was conducted at CLSU. It was attended by 59 participants from various state colleges and universities in Luzon, Visayas and Mindanao. Other participants were representatives from NIA, DENR and LGUs. The national workshop focused on the following:

1. Introduction of the basin approach of assessing and managing water resources.
2. Report of the diagnostic study conducted in UPRB.
3. Workshop to:
    - provide comments on the applicability of the basin approach in other basins.
    - ongoing and planned activities in other river basins.

Future Plans

1. Continue with the operationalization of the UPRBCC, and ensure that the various plans and programs of the council are be pursued.
2. Undertake programs that will further enhance and strengthen institutional capability and improve the agricultural productivity of the Banaag ng Pag-asa IA.
3. Follow up and coordinate the finalization of the proposal developed by participants of the national workshop about the development of effective water-management institutions in other river basins of the country and submit the same to funding agencies for possible funding.

Table 2. Information discussed during the TSAG meetings, Banaag ng Pag-asa IA.

Date	Place	Matters taken up	Attendance (%)
09/12/01	Pamaldan, Cabanatuan City	Objective of strengthening the organization Need to rehabilitate the 4–5 km farm-to-market road not included in first resolution made and approved by the Governor Problem in their mini dam Rehabilitation of canal Schedule of the next meeting Agenda for the next meeting	36
09/14/01	Rajal Norte, Sta. Rosa	NIA's IMT program and the CLSU-IWMI research project Strengthening of IA for effective water management Problem of heavily silted farm ditches	24
09/19/01	San Pablo Matanda, Aliaga	NIA's IMT program and role in providing irrigation service and the CLSU-NIA-IWMI-funded research project Strengthening of IA Need to rehabilitate the farm-to-market road Schedule of the next meeting Agenda for the next meeting	37
09/20/01	San Pablo Bata, Aliaga	NIA's IMT program and role in providing irrigation service and the CLSU-NIA-IWMI-funded research to strengthen IA Need to rehabilitate the mini dam or "pritil" Presence of illegal turn-outs Desilting of lateral AM3 President G.M. Arroyo's program	36
09/27/01	Pamaldan, Cabanatuan City	Review of the minutes of the previous meeting (September 12, 2001) NIA's IMT program, constitution and bylaws Identification and presentation of officials Resolution requesting for the repair of the farm-to-market road Schedule of the regular meeting	64

Continued

Table 2. Continued.

Date of meeting	Place of meeting	Matters taken up	Attendance (%)
09/28/01	San Pablo Bata, Aliagathe	NIA's IMT program and role in providing irrigation service and the CLSU-NIA-IWMI-funded research CLSU as a government institution of higher education and a center for generation/ development and promotion of technology Strengthening the IA ISF collection problems President Arroyo's program	100
10/12/01	Cinco-cinco, Cabanatuan City	NIA's IMT program and CLSU-NIA-IWMI-funded research CLSU as a government institution for students and center for technology promotion Strengthening the IA Problems on water management and distribution	27
10/23/01	Rajal Norte, Sta. Rosa	NIA's IMT program and CLSU-NIA-IWMI-funded research Strengthening of the IA Illegal turn-outs Rehabilitation of only one lateral Desilting of lateral AM3 ISF payment and collection problems	50

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Developing Effective Water-Management Institutions in River Basins: Case Study of Deduru Oya, Sri Lanka

K. Jinapala and P. G. Somaratne[1]

Introduction

This paper synthesizes the findings of a study conducted in the Deduru Oya river basin during 1999–2001 under the Asian Development Bank (ADB)-assisted Five-Country Regional Technical Study (ADB-RETA 5812). This section introduces the objectives, methodology and description of the Sri Lanka case study. The next two sections discuss the physical and socioeconomic characteristics of the basin and their implications for the performance of institutions. The fourth section offers an institutional analysis and discusses implications of institutional performance on water-resources management. The final sections propose institutional reforms required for integrated water resources management, discuss actions initiated by IWMI in this direction, and present some concluding remarks.

Sri Lanka Case Study and Its Objectives

Deduru Oya is a seasonally water-scarce river basin in which the agriculture sector is the major water user. There are no critically competing demands from other sectors such as industry, fishery, domestic use, or environment to pose a threat to the agriculture sector. However, the research indicates trends for future competition for water from other sectors, especially from domestic use, environment and industry. The major thrust of the institutions in the basin is to manage the present and future demands for water from different uses such as food production and ecosystem maintenance. In this context, this case study attempts to achieve two objectives.

The first objective is to contribute to international knowledge on poverty eradication, resource conservation, and environmental protection in developing countries. This goal will be promoted through increasing equity and productivity in water use, and by developing and strengthening policies and institutions for improved and sustainable management of water resources. The second set of objectives is specific to Sri Lanka and includes the following:

- Identify policies, support services, and institutional improvements that will lead to improved management of irrigation and other uses of water in the selected basin.
- Support efforts of national and basin-level stakeholders to implement institutional and policy improvements and reforms.

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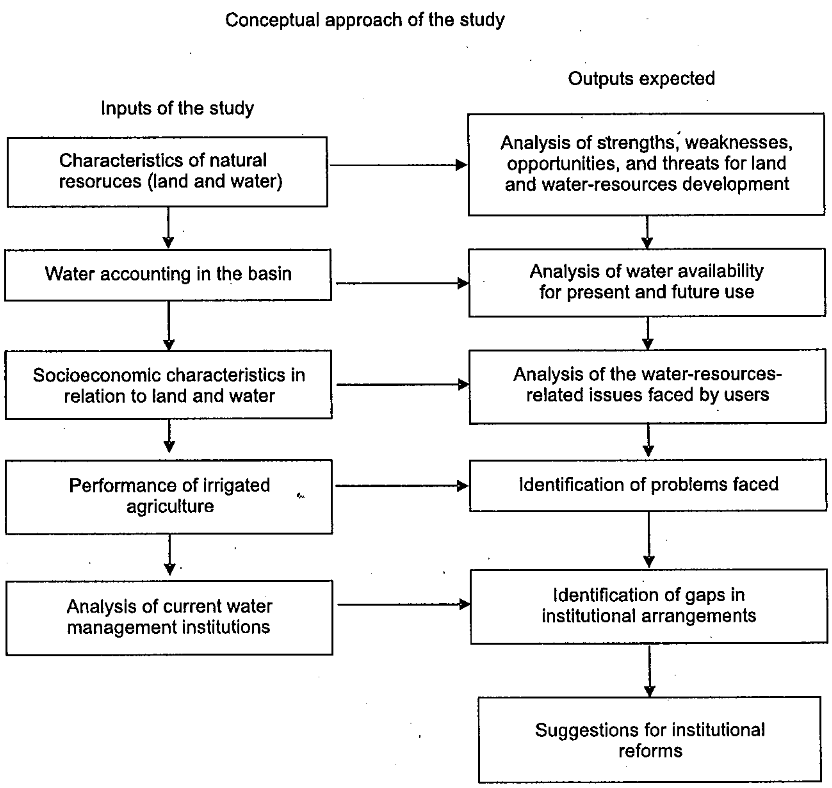
- Develop and validate a replicable methodology combining participatory and technical analyses, which can be used to plan improvements in river-basin management.

This work will also help implement the proposed new water-resources policies formulated by the Water Resources Secretariat (WRS) funded by the ADB.

Methodology

The main purpose of the case study is to help relevant stakeholders to identify the reforms and changes required in existing water-resources management institutions in the basin specifically, and in the country in general. To understand the current performance of existing institutions in managing natural-resources-based development in the basin, several studies were conducted during the first phase of the study. Challenges likely to emerge in the future for the existing institutions in carrying out resources-management functions were also identified through these specific studies. The contributions of each specific study in achieving overall objectives of the main study are shown in figure 1.

Figure 1. Framework adopted in the study.



Description of the Studies

In the context of this study, the main function of the institutions is to manage the human interventions within the natural environment in the basin. As a basis for evaluating the efficiency of the existing institutional mechanism, there is a need to better understand these human interventions and the way such interventions are managed by the existing institutions. The studies mentioned in figure 1 analyzed the institutions to obtain a comprehensive understanding. Examples of human interventions and the nature of the environments in which these interventions are implemented are given in table 1. The following section discusses significant findings and their relevance to the performance of institutions.

Table 1. Examples of human-intervention activities and the related environments.

Environment	Human interventions in the environment
Physical	Development of water resources for various uses, such as agriculture, industry and power generation, etc. Utilization of land for agriculture.
Biological	Utilization of forest resources for various activities, and for animal and human use.
Social	Population increase, social equity, distribution of resources, income generation and livelihood activities.

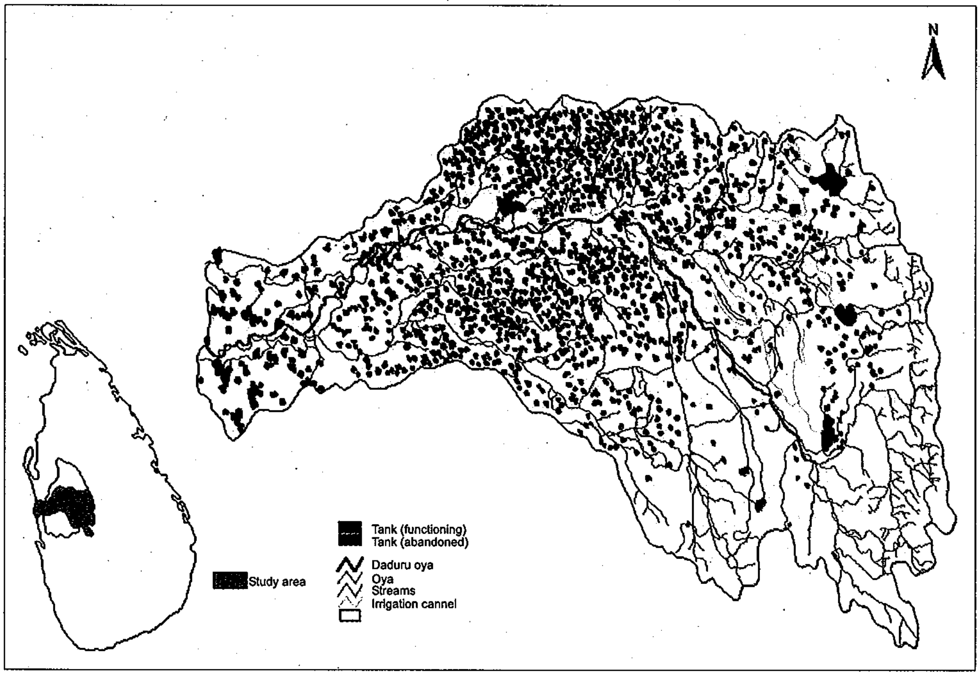
Physical Characteristics of the Basin

Significant Findings

The Deduru Oya basin area covers about 2,700 square kilometers. The Deduru Oya river with 14 tributaries is the main hydraulic feature of the basin. Rainfall is the only source of water and there are no trans-basin diversions into or out of the basin. The average annual rainfall in the basin is about 1,600 mm, ranging from 50 mm in a dry month to 280 mm in a wet month. Rainfall varies spatially, but there are no data from representative geographical locations to support spatial variations in rainfall. Generally, the tail-end and head-end areas of the basin receive comparatively more rain than the middle areas (figures 2 and 3).

The western side of the basin and areas towards the tail-end portion of the basin, with a deep weathered soil profile and sandy soils, are capable of retaining a substantial quantity of groundwater in the regolith. The north-central part of the basin has comparatively thin regolith soil and less groundwater. Salinity and hardness of groundwater are a problem, especially in the western part where the groundwater table is not deep. In the middle portion of the basin, water is contaminated with fluoride and iron. Depletion of groundwater is reported in many parts of the basin due to excessive sand mining of the river. Saltwater intrusion is a serious problem in the tail-end areas where the river has been deepened due to sand-mining activities.

Figure 2. Hydrography of the Deduru Oya basin.



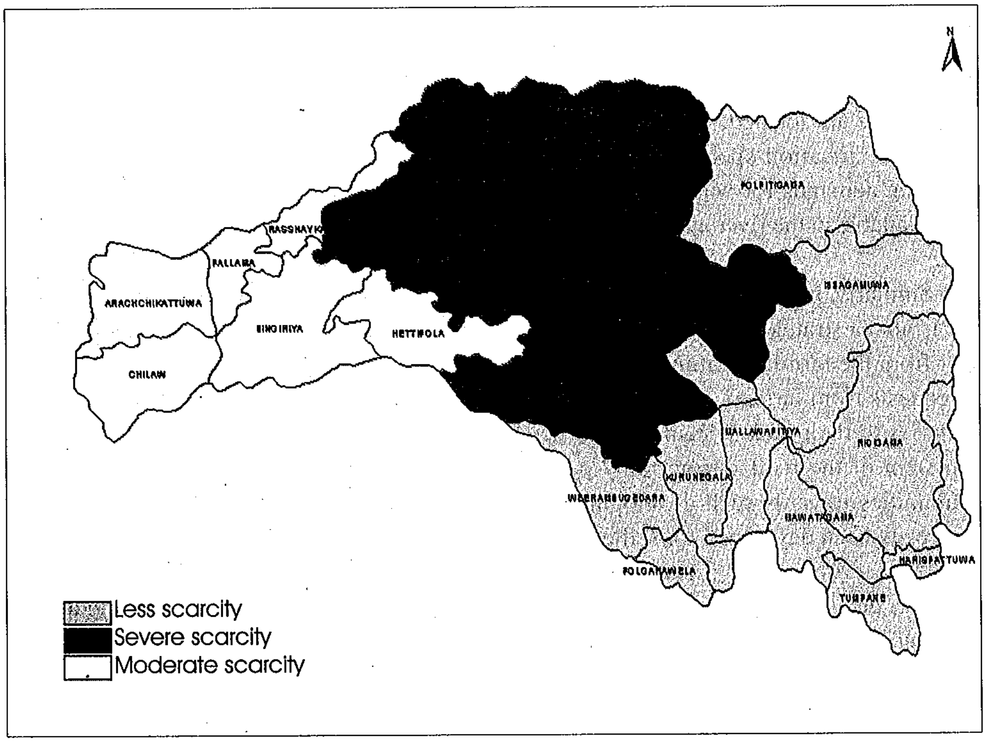
The total land area of the basin is about 262,250 hectares out of which 239,810 (91%) have already been developed and used for various economic activities such as residences and agriculture. The rest, 22,440 hectares, is undeveloped land; of this, except for about 1,500 hectares of barren land, the rest is categorized as forest, wetlands and water bodies. The largest area (36%) of developed lands in the basin is used for coconut cultivation while the second largest (19%) is used for paddy cultivation. The details of land use in the basin are shown in table 1 in the annex.

Water-resources development for irrigated agriculture started in the basin during the days of ancient kings. There is historical evidence for the existence of a large number of small and medium tank systems in the basin. Therefore, construction of tank systems of different scales can be considered to be the first step in irrigation development.

At present, there are four major reservoirs, depending on diversions from the main stream of Deduru Oya and two of its main tributaries, as well as several medium tanks and about 1,500 small tanks scattered through the basin. As a result of tapping almost all the potential surface-water resources for the development of these tank systems, there is little possibility for further development of tanks in the basin. Attempts have been made to increase the cropping intensity in the command areas of tanks through improvement, rehabilitation and water management.

Due to a shortage of surface water for irrigation development, the government and farmer communities have now shifted their focus to the development of groundwater resources and lift irrigation systems for agriculture. IWMI studies in the basin indicate that there are about 5,140 agricultural wells and 2,609 river lift pumping systems in the basin. An increasing trend for the use of these two water sources for lift-irrigation-based agriculture is observed in the basin at present. There are no restrictions by the government authorities on river lift irrigation or construction of agricultural wells for tapping groundwater resources. Figure 3 shows the spatial distribution of water scarcity in irrigation systems.

Figure 3. Spatial distribution of water scarcity in the Deduru Oya basin.



Demand for water by the industrial sector is low due to the slow tempo of industrial development in the basin. The small-scale industries in the basin use water from domestic wells or irrigation canals. Demand for water from the domestic sector is on the increase. However, only about 5 percent of the communities in the basin have access to piped water supplies. The National Water Supply and Drainage Board (the agency with a mandate to create infrastructure for domestic and industrial water use) has constructed about 2,000 tube wells in the basin for domestic use.

Pollution of water in some tributaries, such as the Maguru Oya, poses a major problem for augmenting domestic water supply schemes in some water-scarce areas of the basin. The main reason for water pollution in the basin is the discharge of solid waste and wastewater into natural drains and streams from the urban centers such as the Kurunegala town.

Basin-level water accounting studies conducted by IWMI reveal that about 300–400 million cubic meters (MCM) of water go out of the river basin within a relatively short period of time during the wet season. Table 2 in the annex gives details of water accounting. During the greater part of the year the river runs dry in the middle portion of the basin, below the Ridi Bendi Ela anicut. However, water is available in the tail-end part of the river for the greater part of the year because there is inflow into the tail of the river from some tributaries. Drainage water from irrigation systems located in the middle and upstream areas also flows into the tail portion of the river.

Implication of Hydrological Conditions for Institutional Performance

Managing relatively scarce water resources is the challenge faced by water-sector institutions. Water scarcity seriously affects the middle portion of the basin in which most of the small tank systems are located. Groundwater is also scarce in this part of the basin. This creates a demand for location-specific water-resources-management strategies in the future. With increasing demands for water by other sectors, such as industrial and domestic, allocation of water available in the river and its tributaries will be a difficult task for the institutions managing water.

Similarly, implementing irrigation-development programs that tap the excess water in the river is also a strategically challenging task for the institutions, as there are demands for this water from the farming communities in different locations along the river. For example, there are requests from farmers cultivating under small tank commands asking to divert water from tributaries to their tank systems. Construction of large reservoirs tapping excess water in the main stem of the river during rainy periods would create an unpleasant attitude in farming communities towards such developments. As most of the available land (91%) in the basin has already been developed for settlements, cultivation of coconut and other uses, construction of large reservoirs would seriously affect established settlements with permanent cultivation. Therefore, decision making for water-resources development in the face of competing demands under current socioeconomic conditions is a real challenge for the institutions.

Water management in major tank systems is reported to be satisfactory at present. However, with increasing demand for water by other sectors, the irrigation sector will have to compete for this demand. There will be pressure on institutions to improve the productivity of water resources. Under the circumstances, irrigation users will be required to use water more efficiently and increase productivity of water resources.

Managing limited groundwater resources is another task for the institutions. The full potential of this limited resource has not yet been realized in the basin due to various socioeconomic reasons. However, there are possible threats of deterioration and depletion of this scarce resource due to lack of institutional mechanisms to monitor and regulate groundwater development activities.

Deterioration of surface-water quality is reported from different parts of the basin. This is a serious situation since groundwater in many parts of the basin is not suitable for drinking due to salinity, alkalinity and other problems. If water quality continues to deteriorate at present rates, it will be very difficult to provide drinking water to the people in the basin. At present, there is no institutional mechanism directly responsible for monitoring and regulating water pollution in the basin. This is a very important task that should be undertaken through water-resources-management institutions in the future. Similarly, river resources are being damaged through sand-mining, brick-making along riverbanks, and other undesirable development activities. These activities are carried out without proper monitoring. This is also an area for intervention to improve water-resources-management institutions.

Socioeconomic Conditions

The total population in the basin is about 1.4 million. The average population density in the basin is 378 persons per square kilometer. Comparatively high population densities are observed in the head end and the tail end of the basin, comprising urban and semi-urban centers. Sixty percent of families in the basin have 4–5 members in each family. Population growth rate in the basin ranges from 1 to 1.5 percent per year. Out of the total population, about 256,000 (39%) are within the 19–45 age group. Educational achievement is high for the populations living in and around towns and urban centers with better education facilities.

Nearly 90 percent of the population in the productive age group are involved in different types of livelihood activities. Only 10 percent are reported as unemployed. The majority of the employed people are involved in agriculture-related income-generating activities (43% in the Kurunegala district and 36% in the Puttlam district). The other income-generation activities of people in the basin are shown in table 3 in the annex. The significance of agriculture as a main income-generating activity is diminishing in many areas of the basin, in the view of community members. The changes in their income- generating activities as observed by the farmers are shown in table 2.

Table 2. Main income-generation sources of the sample householders.

Main income sources	Past 10 years (%)	Present (%)	Change
Agriculture	76	45	Significant
Wage labor	10	14	Moderately significant
Govt./Private-sector employment	11	27	Significant
Livestock	1	1	No change
Foreign employment	1	2	Significant
Self employment	6	17	Significant
Govt. welfare assistance	0	1	Significant

Source: Household survey in small tank systems.

Communities in the basin are multiple water users whose livelihood activities are dependent upon water availability in the basin. They include farmers under major, medium, minor, and lift irrigation systems, those who cultivate paddy and other crop varieties under rain-fed conditions, and cultivators of coconut and other permanent crops. In addition, there are people in the basin involved in livestock keeping and fishing in irrigation systems. Coconut and rice-based industries, brick- and tile-making, and other diverse small-scale industries are also found in the basin.

In addition to different water-use sectors, there are other groups whose livelihood is dependent upon river resources. They include people involved in sand-mining in the river and brick-making along the bank of the river. They too have a stake in the use and utilization of river resources. Their activities are carried out without being properly monitored and regulated in a responsible manner, so that they have already created serious ecological problems like soil erosion, groundwater depletion, and seawater intrusion into the basin.

The total command area under major irrigation systems is approximately 6,000 hectares and accounts for 13 percent of the irrigated area in the basin. Out of four major irrigation systems in the basin, farmers in three systems have no serious problems concerning irrigation water, and generally cultivate two crops a year in many instances. Out of the four major irrigation systems, two systems, Batalagoda and Kibulwana, have 100 percent cropping intensity in both seasons. Out of the two remaining systems, 10-15 percent of the command area in Ridi Bendi Ela is not cultivated with paddy in *yala* (dry season). However, non-paddy crops are cultivated now in the remaining portion of the command area that normally goes fallow in yala. Cultivation of the full command area of Hakwatuna oya major irrigation system is not possible in yala due to water scarcity. The average yield under major irrigation systems is about 3.4 t/ha in yala and 4.4 t/ha in *maha* (wet season). The gross income is about Rs 38,095/ha in yala and Rs 41,000/ha in maha (US$1.00 = Rs 95.00). Farmers in these schemes have a profit of Rs. 20,000 (US$ 210)/ha in yala and Rs. 21,000 (US$ 220/ha) in maha.

Paddy lands under small tank systems cover around 11,000 hectares (26% of the irrigated area under the basin). The number of families cultivating under small irrigation systems is about 36,700. This indicates that the average per capita holding per family is about 0.3 hectare. The cropping intensity under minor tank systems in maha is about 75–80 percent while it is very much less (below 50%) in yala. Agriculture under small tank systems faces problems such as land fragmentation, low yield and low cropping intensity. Due to the less-rewarding nature of paddy cultivation under small tanks, members of the younger generation in these tank villages are not willing to make farming their livelihood. They try to find employment outside the village.

During maha, farmers in the middle portion of the river basin practice shifting cultivation. Though this was a major livelihood activity of the farmers in the past, it is less rewarding due to the nonavailability of lands under long fallow periods suitable for shifting cultivation. In addition to cultivation of paddy under irrigated and rain-fed conditions, most farmers in the basin have some coconut trees, cultivated at least in their homesteads. Coconut cultivation is highly concentrated in the tail-end areas of the basin. While it is a major income source for farmers with large landholdings, it provides a supplementary income to marginal farmers cultivating under small tank systems in the basin. Household survey data in small tank communities in the basin show that the annual income of a household from coconut cultivation ranges from Rs 5,000 to 35,000. However, factors such as drought in yala, lack of programs for soil and water conservation in coconut lands, land fragmentation, and sale of coconut lands for residential purposes have adversely affected coconut cultivation in the basin.

Livestock keeping is also an important livelihood activity of the people in the basin. Livestock includes mainly cattle, poultry and goats. Poultry keeping has become a major income-earning activity in water-scarce areas like Kobeigane in the middle portion of the basin. However, water scarcity in yala is still a problem for cattle-rearing in the middle portion of the basin.

Another major problem in many parts of the basin is the nonavailability of safe drinking water. Only 5 percent of households have access to piped water supplies. However, most of these schemes do not provide fully treated drinking water. Groundwater in the tail end and middle portions of the basin is contaminated and not suitable for drinking. People in water-scarce areas have serious problems with drinking water during drought periods when wells and streams run dry.

Poverty in the Basin

According to data from the government *Samurdhi* program for poverty alleviation, about 60 percent of families in the basin are below the poverty level and receive government assistance. Pockets of poverty are found mainly in the water-scarce middle portion of the basin. Farmers in these areas can cultivate only one crop a year and they cannot grow permanent crops like coconut due to water scarcity. Due to these reasons they cannot have a regular income throughout the year. The tail-end portion is comparatively rich due to the availability of groundwater for cultivation of other field crop (OFC) and the existence of large-scale coconut plantations. A similar poverty situation is observed in semi-urban areas close to the Kurunegala municipal area. These areas are characterized by smallholdings, unemployment and high population density.

Implication of Socioeconomic Conditions for Institutions

The major challenge for the institutions involved in community development in the basin is to address poverty-related issues in the poverty-stricken areas in the basin. There is a need to launch programs to help youths in the areas to find employment, and create opportunities for poor families to start income-generating activities (mainly nonagricultural ones) through special projects for poverty alleviation. National-level planning may be required in this case, as absorbing the growing population into the agriculture sector is no longer possible due to various reasons. Shortage of land and water resources is one main constraint for expansion of agriculture. Unwillingness on the part of youths to make agriculture their main employment is also a serious constraint. They view agriculture as less rewarding. Institutions managing resources in the basin need to pay special attention to address poverty issues, as poor groups tend to exploit natural resources intensively for their livelihood in the absence of alternative employment opportunities.

Institutional Analyses

A large number of sector-based institutions exist in the country for management of water and other natural resources. These institutions include not just organizations, but policies, rules and regulations. The organizations function at various levels such as national, provincial, district, and divisional, with branch offices. In some cases, power and authority vested in some organizations through ordinances, rules, and regulations have been delegated to provincial, district, or divisional levels for carrying out resources-management tasks. In some cases, authority and power lie with the central government authorities. The main organizations involved in water and other natural-resources management in the basin are presented in table 3.

Table 3. Basic information on organizations in the basin.

Name	Type of organization	Area of jurisdiction
Irrigation Department	National	Irrigation Engineer's (IE) Division
Irrigation Management Division	National	Irrigation Scheme
Department of Agrarian Services	National	Divisional Officers Division (Administrative Division)
National Water Supply and Drainage Board	National	District Level
Environmental Authority	National and Provincial	National and Provincial Levels
Water Resources Board	National	National
Cost Conservation Department	National	National
Pradeshiya Sabhas	Local Government Divisional Body	

In addition to the main agencies mentioned in table 3, there are a large number of organizations indirectly involved in the use, utilization and management of land, water and other natural resources for production. Some of these organizations include the Department of Agriculture, the Department of Animal Production and Health, Samurdhi Authority, Coconut Cultivation Board, Agriculture Development Authority, Forest Department, Cashew Corporation, and Minor Export Crop Development Department. In addition to these sectoral organizations functioning at different levels in the basin, there are three-tier coordination committee systems established to support planning, implementation and monitoring of agricultural-development programs. This committee system includes the Agrarian Development Committees at the grass-roots level, Divisional Agricultural Committees at the divisional level and District Agriculture Committees at the district level. Representatives of government organizations, nongovernmental organizations (NGOs), and community-based organizations in the respective areas attend monthly meetings of these committees.

There are large numbers of branch offices of the main line agencies in the basin area. For example, in nine Divisional Secretary (DS) divisions studied, there are nine DS offices, nine agrarian development centers, nine Pradeshiya Sabha offices, six branch offices of the Department of Animal Husbandry and Health, two offices of the Department of Irrigation and two project offices of the Irrigation Management Division.

International and local NGOs have very limited involvement in the development activities in the basin. A large number of community-based organizations (CBOs), such as Farmer Organizations, Milk Societies, Cooperative Societies, *Kapruka* Societies (coconut growers' associations), Samurdhi groups and Environmental Associations, operate in the basin area. For example, there are 1,225 CBOs in nine DS divisions from which data on institutions were collected.

There are nine major legal acts related to natural-resources management in which water-resources management has been a major component (table 4, annex).

Implications of Institutional Performance for Water-Resources Management

Absence of mechanisms to integrate activities of sector organizations in the basin is seen as the major institutional gap in the existing institutional framework. The existing organizations and legislation are adequate to manage development activities related to water resources. However, a system is required to manage the implications of water-resources development taking place in different location on the basin as a whole. The functions of current organizations are more concentrated on resources utilization and development rather than on managing the implications of development on the environment, its sustainability, and negative impacts on different stakeholders in different locations in the basin. Institutional mechanisms are also required in the present context for productivity of water in irrigated agriculture, which is the main water-use sector in the basin. These circumstances demand changes in institutions for use, utilization and management of water in a basin context.

Initiating IWRM

As discussed in the foregoing sections of this report, the Deduru Oya river basin presents us with a large number of water-resources management problems and institutional weaknesses associated with them. Most of these institutional weaknesses are not specific to the Deduru Oya basin alone but are manifestations of "sector-based development," a mode of development and management of water and other natural resources in the country up to recent times. Therefore, the main focus of the study during the action phase was on the identification of changes required in the existing institutions to address IWRM issues in the basin. Based on the findings of the study, the reforms required in the institutions are proposed in this section with appropriate methods for introducing such reforms. Also the report further discusses the activities initiated so far by IWMI and future actions to be implemented by the Water Resource Secretariat (WRS) for establishing IWRM in the basin.

Changes Proposed in Institutions

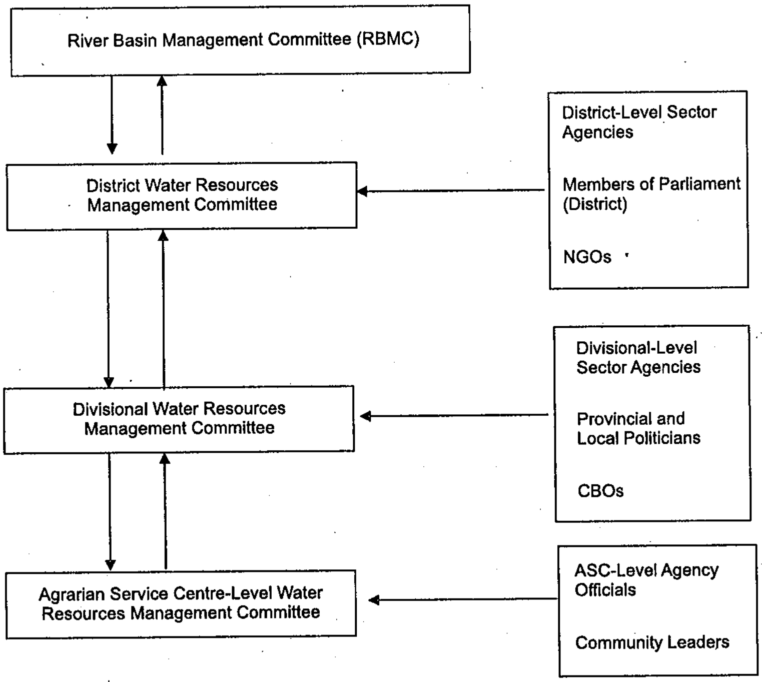
It is widely recognized that effective management of water resources requires basin-level organizations. However, experience with river-basin authorities suggests that they are difficult to sustain (Barrows 1998). This situation is seriously considered in the institutional reforms proposed in this paper. As an attempt in this direction, structural changes that bring vast changes in the existing institutional framework have been avoided to the maximum possible extent in the proposed institutional reforms. Instead, functional changes are proposed in the existing organizations to carry out IWRM activities effectively.

The major structural changes proposed by the WRS are the establishment of the National Water Resources Authority (NWRA), Water Resources Council (WRC), and Water Resources Tribunal (WRT) at the national level. These apex organizations would be responsible for water-resources planning, and for the management and implementation of regulatory measures. They would be independent from those agencies that are responsible for specific water-using sectors like irrigation and domestic water supply. The NWRA is responsible for clearly defined policy and regulatory functions regarding water resources and the WRC for coordination and advisory functions while the main tasks of WRT are to resolve appeals regarding the allocation of water and arbitrate in water-related disputes. The major structural change proposed for the river basin level is the establishment of a River Basin Management Organization (RBO), the institutional framework of which is shown in figure 4.

The RBO is the apex body at the basin level for water resources planning and management. An RBO can be established for one or several river basins and groundwater aquifers (or parts thereof) irrespective of whether they are provincial or interprovincial ones. It can be either a temporary body or a permanent establishment with a limited number of professionals in different disciplines such as hydrology, irrigation management, institutional development, and environmental science. In case the RBO is a temporary body that would withdraw after the establishment of IWRM there should be a central-provincial- or district-level body to take over the functions of the RBO once it is withdrawn. The major functions proposed for the RBO are as follows:

- Preparation of river basin plans—the RBO is expected to prepare a master plan for the river basin/s, under the guidance and assistance of the NWRA.
- Monitoring the activities of other agencies to ensure compliance with river-basin plans and national policy for IWRM.
- The RBO refers appeals regarding the allocation of water and water-related disputes to the WRT for resolving and arbitration.
- Communication with district- and lower-level coordinating bodies on monthly, quarterly or annual bases for effective IWRM in their jurisdictions.
- Maintaining data bases required for basin-management purposes.
- Working with the Central and Provincial Environmental Authorities for water-pollution control.

Figure 4. Proposed new organizational structure for the Deduru Oya basin.



The next level of the institutional framework for basin management is the District Water Resource Management Committee (DWMC) headed by the District Secretary of the relevant district. The proposed DWRC is not a new committee. It is the District Agricultural Committee (DAC) that will be strengthened to handle IWRM activities under the proposed institutional reforms. At present, the DAC comprises district-level officers of agencies involved in agricultural plan implementation and district-level representatives of CBOs like farmer organizations. Under the proposed reforms, the committee will include the district-level officials of the government, provincial and local government agencies involved in the development and management of land, water and other natural resources, representatives of NGOs, private-sector organizations and CBOs. It is necessary to make this committee a legal body with authority and power to plan, implement, and monitor IWRM activities and not just a coordinating meeting. In addition to its present roles and functions related to agricultural plan implementation, it would be responsible for IWRM in the district. The new roles and functions proposed for the DWMC are as follows:

- Responsible for planning, implementation and monitoring of IWRM activities at the district level. It will monitor the activities of other agencies working in the district to ensure compliance with river-basin plans and national policy for IWRM. The issues related to the depletion and deterioration of surface water and groundwater resources, and damages to river resources, will receive the attention of this committee. The NWRA and other relevant government agencies will delegate the power and authority required for implementing IWRM activities to the DWMC.

- Establish links with the RBO and provide feedback on IWRM activities in the district.
- Communicate with the Divisional Water Resources Management Committees that provide feedback on IWRM activities at Divisional Secretary level to the DWMC.

The level below the DWMC is the Divisional Water Resource Management Committee, headed by the Divisional Secretary of the respective DS division under the basin. As with the DWMC, this committee too is not a new one. It is the DS-level agricultural committee that will be strengthened to take up IWRM activities at the DS level. At present, this committee is represented by divisional-level officers of agencies involved in agricultural plan implementation. Under the proposed reforms, the committee structure will be widened to include the divisional-level officers of the national, provincial and local government agencies involved in the development and management of land, water and other natural resources, representatives of NGOs, private-sector organizations and CBOs. Its functions are similar to those of the DWMC. However, as far as field implementation and monitoring of IWRM activities are concerned, this is the most important and crucial level. This committee needs to be strengthened by devolving authority and power vested at national, provincial and district levels, by allocating resources and by developing knowledge and skills of the officers through appropriate training for effective IWRM. Separate units need to be established at this level for monitoring IWRM and other development activities and institutional development for IWRM.

The next level below the DS level is the Agrarian Development Center level. Development committees comprised mainly of farmer representatives and agency officers involved in agricultural development. These committees should establish links with the Divisional Secretary Level Water Management committee through representation. They can represent IWRM issues related to major, medium and minor irrigation systems in a DS division at the DS level. Officers, such as Divisional Officers (DOs) and Agriculture Production and Research Assistants, can play a leading role in the institutional development unit at DS level by providing training on IWRM to various CBOs.

The grass-roots level comprises organizations of resource users. The organizations such as farmer organizations, fisheries associations, and sand miners' organizations can have representatives on DS-level committees and be involved in planning, implementation, and monitoring of development activities within an IWRM framework. The Institutional Development unit to be established at DS level should work closely with these CBOs and strengthen them for IWRM.

Actions Initiated by IWMI to Establish IWRM in the Basin

The major role played by IWMI during the action phase was to create awareness among the key stakeholders about the water-resources problems in the basin as a whole, and how IWRM can contribute to resolving these problems. After a half-day workshop held with the key stakeholder agencies in the North Western Province to discuss the findings of the ADB-RETA diagnostic phase, agency officers proposed that awareness sessions be held at Agrarian-Center level, DS level and at district-level coordinating committees. Based on this request, awareness meetings were held with Agrarian Development Committees and divisional-level agricultural committees at Ridiyagama, Ganewatte, Wariyapola, Nikaweratiya, Bingiriya and Chilaw DS divisions. An awareness session was held with the DAC at Puttlam. Though the officers were aware of the problems in their areas, they were less aware of the problems in the basin as a whole; hence, awareness creation was required to explain the relevance and importance of IWRM concepts and a river-basin organization as a means to find solutions to these problems.

During the awareness-creation sessions, institutional problems related to water-resources management were discussed in detail. The stakeholders proposed ways and means to overcome these institutional problems by strengthening the existing institutions rather than by creating new ones. It is on the suggestions of the stakeholders that strengthening of the DS level for planning, implementing, and monitoring of IWRM and other development activities is proposed here.

Another main activity during the action phase was to identify new roles and functions for the institutions that would take responsibility for IWRM activities. These new roles and functions were proposed by stakeholders to fill the existing gaps in the institutions.

Actions were pursued to carry out several studies based on the recommendations made by the stakeholders. They included a study on lift irrigation using groundwater and surface-water resources, a study on water quality, and another study to review legal provisions for the North Western Provincial (NWP) Council to set up a basin organization for Deduru Oya, which is an interprovincial basin. Out of these studies, the study on lift irrigation and the study to review legal provisions have been successfully completed. The study on lift irrigation revealed that a large number of agricultural wells and river lift systems are in operation in the basin even though they do not appear in the records of government organizations responsible for their management. As far as groundwater is concerned, there is no agency responsible for monitoring and regulating groundwater extraction in the basin and in the country as a whole. We recommend that the proposed RBOs should maintain the database on groundwater development and river lift irrigation systems and take regulatory measures concerning groundwater extraction. The database developed by IWMI would be a start for this activity.

The study that reviewed legal provisions came out with the finding that there are no legal impediments that would stand in the way of the NWP authorities proceeding to set up a river-basin organization for Deduru Oya. The study on water quality could not be initiated and remains to be undertaken when the Deduru Oya RBO is established.

Final National Workshop and Summary of Findings

Based on the findings of the diagnostic and action phases of the ADB-funded Regional Technical Assistance Study, the following recommendations were made for the Water Resources Secretariat for pilot testing of a river-basin organization and IWRM in the Deduru Oya basin:

- Reviewing IWMI reports and documents related to the Deduru Oya river-basin study. This will create greater awareness of socioeconomic-institutional- and water-resources-related problems in the basin as a whole.

- Taking these conditions into consideration, the Secretariat needs to initiate a river-basin organization for the Deduru Oya basin, with the consultation of provincial and central government authorities.

- Introducing necessary reforms in district- and division-level agricultural committees for undertaking IWRM activities in consultation with the authorities concerned.

- Initiating action through a river-basin organization and coordinating bodies at the district and divisional levels to regulate activities leading to degradation of water resources, such as sand mining, either through special projects or with the involvement of existing organizations.

- Initiating action to prepare a water-allocation plan and decide water rights, taking the prevailing political environment in the country into consideration.

Conclusions

The action initiated so far by IWMI was to facilitate the institutional-development process for the establishment of IWRM in the basin. IWMI believes that implementation of IWRM activities needs to be undertaken by the water-resources-management agencies in the country by introducing necessary changes in the existing institutional framework for sustainability. Institutional changes themselves may not be sufficient. The proposed institutions need to play a leading role in creating a favorable environment for the establishment of IWRM in the country. Awareness creation on IWRM concepts, knowledge, and skill development to undertake IWRM, commitment and attitudinal changes in the institutions and the members of civil society are also required. Above all, political will is of crucial importance for implementing IWRM concepts in the country. Therefore, the work we all have done so far is only the beginning. We have just embarked on a long journey to establish IWRM in the country.

Annex

Table 1. Land use in the Deduru Oya basin.

Land category	Usage	Extent (ha)	Land distribution (%)
Developed lands		239,810	91
	Build up lands	520	0.2
	Homesteads	35,050	13.4
	Tea lands	240	0.1
	Rubber Lands	4,680	1.8
	Coconut lands	95,560	36.4
	Mixed trees	1,950	0.7
	Paddy lands	48,655	18.6
	Sparsely used croplands (chena and highlands)	50,500	19.3
	Planted forests	2,655	1.0
Undeveloped lands		22,440	9
	Dense forest	4,225	1.6
	Open forest	1,155	0.4
	Scrub lands	4,035	1.5
	Grasslands	55	0.02
	Water bodies	11,410	4.4
	Barren lands	1,420	0.5
	Mangroves	90	0.03
	Marshes	50	0.02

Data received from land-use maps, Survey Department, 1989.

Table 2. Details on water accounting in the basin (data in MCM)

Component	1994 yala	94/95 maha	1995 yala	95 /96 maha	1996 yala	96/97 maha	1997 yala	97/98 maha	1998 yala
Climatic condition	Dry	Avg.	Wet	Dry	Avg.	Dry	Wet	Wet	Wet
Gross inflow	1,202	2,071	2005	1,578	1,745	1,558	2,172	3,031	2,010
Storage changes	259	-179	71	9	40	-40	-9	-150	150
Net inflow	1,407	1,891	2,076	1,587	1,785	1,518	2,163	2,880	2,160
Process depletion	615	985	1,019	842	840	968	967	1,109	969
Non-process depletion (beneficial)	245	305	386	205	401	205	392	319	392
Non-process depletion (non-beneficial)	243	196	255	192	485	116	350	135	299
Uncommitted outflow	358	406	416	349	85	230	454	1,318	500

Table 3. Employed persons by major employment groups, 1997.

Districts	Total	Agriculture		Mining & quarrying		Manu-facturing		Electric gas & water		Construc-tion		Trade and hotel		Transport		Other*	
	(000)		%		%		%		%		%		%		%		%
Kurunegala	554	239	43.2	7	1.2	80	14.5	2	0.4	21	3.83	44	7.9	22	3.9	139	25.0
Putlam	210	76	36.4	5	2.2	43	20.4	-	0.02	14	6.77	25	11.9	10	4.7	37	17.6
All Island	5,608	2,032	36.2	92	1.6	920	16.4	31	0.5	312	5.56	696	12.4	268	4.8	1,257	22.4

*Other activities include individual services, real estate, insurance and miscellaneous.
Source: Department of Census and Statistics: District Profile of Labor Force 1997.

Table 4. Existing rules and regulations for water-resources development and management.

Enactment	Date	Key provisions	Agency/Agencies responsible for implementing legal provisions
The Irrigation Ordinance No.32	1946	The Irrigation Ordinance provides the regulations for the Divisional Secretaries to prepare plans for new minor irrigation schemes or introduce changes to existing schemes. The approval of the Minister is required to prepare plans for major irrigation schemes under the terms of this ordinance. The ordinance also provides for holding cultivation meetings in major irrigation schemes. There are provisions to take seasonal cultivation decisions at a special meeting of an Irrigation Management Division Project Committee (IMD PC) attended by the Divisional Secretary.	Minister of Irrigation, DS, IMD PC
The Crown Land Ordinance (The State Land Ordinance)	1947	The right to use, flow, management, and control of any public lake is vested in the state under this ordinance. It makes a distinction between public and private waters. Part IX of the ordinance provides for the regulation and control of public waters and streams through a system of permits. Water for irrigation is exempted from license requirements.	DS
The Electricity Act No.19 (as amended)	1950	This Act provides for licensing installations for the generation of electricity. These licenses confer all rights necessary for the purpose of electricity generation, including rights to use water.	Ministry of Irrigation and Power

Continued

Table 4. Continued.

Enactment	Date	Key provisions	Agency/Agencies responsible for implementing legal provisions
The Soil and Water Conservation Act	1951	This Act empowers the Minister of Agriculture to declare areas subjected to soil erosion as erodible areas. The Minister may make regulations applicable to these areas requiring the owners of land to take measures to afforest the banks or watercourses or to maintain a strip of land along the banks of watercourses free from cultivation.	The Minister of Agriculture
The Agrarian Service Act (as amendment and continuation of the Paddy Lands Act No.1 of 1958)	1979	Provides for tenure security in irrigated lands and sound management of agricultural activities and water in small tank systems through Agrarian Service Committees and Farmer Organizations.	Commissioner of Agrarian Services
The Mahaweli Authority of Sri Lanka Act, No. 23 (as amended)	1979	This Act empowers the Mahaweli Authority to use and develop the water resources of the Mahaweli river.	The Mahaweli Authority
The National Water Supply and Drainage Board Act No. 2 (as amended)	1974	This Act empowers the National Water Supply and Drainage Board (NWS&DB) to direct and use water to provide water supply for public, domestic and industrial purposes without other approval.	The NWS&DB
The National Environment Act (as amended)	1988	Provides for environmental pollution control, including the pollution of water and protection of sensitive habitats such as lagoons and lakes.	The National Environmental Authority (authority over some activities has been delegated to Provincial Environmental Authorities).
Participatory Irrigation Management Policy	1988	Provides direction for handing over of full responsibilities over O&M and resource mobilization below distributary canals to farmer organizations.	Irrigation Management Division and Irrigation Department

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Institutional Arrangements for Water Management in the East Rapti Basin, Nepal

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Physical Characteristics

The East Rapti river basin (ERRB) has a catchment area of about 3,200 square kilometers. The East Rapti river course starts with a very steep slope in mountainous areas and flattens on the way out to meet the Narayani river. The lower reach of the river has mild slopes and larger discharges as many tributaries join its course. Consequently, the river has relatively higher velocities of water in the upper reaches than in the downstream reaches.

The water accounting computations indicate that the basin is an "open basin" (Adhikari 2002). In a typical dry year, only 53 percent of the available flow in the basin is depleted, allowing the rest (47%) of the utilizable flow to move out of the basin. This indicates a potential to harness this utilizable outflow. Also, as only 6 percent of the depleted water is process-consumed, there is a potential to further increase the process-consumption. The study also pointed out that there are substantial spatial variations in water availability compared to temporal variations within the basin.

There is an inflow into the basin upstream through the tailrace of the Kulekahni hydropower plant built into the adjacent Bagmati river basin. Kulekhani-I and II hydroelectric power plants are located in the upstream catchment area of the basin near Bhainse in the Makawanpur district with an installed electrical capacity of 60 MW and 32 MW, respectively. This is a large water storage hydroelectric power station with catchment and reservoir areas of 126 and 2.2 square kilometers, respectively. One 114-m high rock-fill dam has been constructed in the Kulekhani river to store a gross volume of 85 million cubic meters, which ultimately drains to this basin via the two hydroelectric plants.[3] The water of the Mandu river of this basin is also added to the drain from the first hydroelectric plant while being diverted to the second power plant. Consequently, water in the Mandu river downstream from the diversion point has become insufficient for running about 10 privately run water mills, for which compensation was paid by the power plant.

The population density is 145 persons per square kilometer and has been increasing at the rate of more than 2.8 percent every year due to people's influx into this area (Ghimire et al. 2000). The basin has been experiencing a population influx from different parts of the country from the 1950s with a state-supported resettlement program and the trend is continuing. Promising farming land is still available in the basin area and people like to settle down in this

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[1]Senior Divisional Engineer, Water Energy Commission Secretariat.

[2]Research Coordinator, IWMI/Nepal.

[3]Recently, it launched the "Kulekhani Disaster Prevention Project" to protect the catchment area.

land. The rate of urbanization is also relatively high, and about 23 percent of the population lives in urban areas, compared to the national average of 15 percent. The literacy rate is about 40 percent. Forty two percent of the population is below the poverty line (earning less than NRs 2,500/capita/year; US$1.00 = NRs 78). Only about 36 percent of the population has piped water supplies.

The land use pattern in the basin indicates an extensive presence of forest (39%) followed by agricultural land (27%) and National Park land (27%). The basin has a diverse biophysical environment by gradients, altitudes, landforms and soil types.

The average farm holding size is 0.9 hectare per household and over 75 percent of the population is engaged in agriculture. More females (87%) are found engaged in agriculture than their male counterparts (67%). The land distribution pattern in the basin is highly skewed (Ghimire et al. 2000). About 46 percent of the farmers own less than 0.5 hectare each, amounting to only 16 percent of the total cultivable land whereas 6 percent of households own more than 2 hectares each. It was found that a significant propotion of (over 75% of the population is engaged in agricultural activities) the population has either no access to land or own only a small amount of land. Therefore, land-tenancy arrangements are commonly practiced in the basin area.

As mentioned earlier, about 27 percent of the basin area is under agricultural cultivation (Adhikari et al. 2000; RTDB et al. 2000; Ghimire et al. 2000). It is estimated that only 45 percent of the total cultivated area (about 86,000 ha) in the basin is irrigated, and only about half of it receives year-round irrigation services.

The irrigation systems that divert water directly from the East Rapti river have adequate water supplies (as per the farmers' need) whereas almost all the irrigation systems diverting water from its tributaries have less-assured and limited water supplies, below the farmers' needs (Adhikari et al. 2000). Consequently, river-fed irrigation systems have better productivity in all cereal crops: rice, maize and wheat.

Emerging Trends

Growing Seasonal Water Scarcity

The basin experiences seasonal water scarcity for agriculture. Surface irrigation systems are stressed for required water supplies during the dry season. Consequently, many irrigation water users' groups are making extra efforts to augment water supplies from alternative surface sources and groundwater. The stress has also increased because of growing water demands from other sectors.

In addition, high spatial and temporal variations in water availability are forcing farmers of some areas to look for alternative cropping patterns. Although rice has a low water use efficiency, for a variety of reasons, it is cultivated as the main crop in dry areas by poor people. Despite many irrigation infrastructures, lack of dependable sources and unreliable supplies have, in many cases, resulted in failure of maize crops, particularly in dry areas during the spring season. Due to low evaportranspiration requirements of winter crops and substantial efforts to manage water for rice during the monsoonal season, farmers of relatively dry areas experience more water scarcity during spring than during other seasons.

Marginalization of Fishermen

Bote and *Danuwar* groups depend heavily on fishing. However, the number of fish has been decreasing over time (Ghimire et al. 2000). The main reasons for this are pointed as floods, dam construction in Narayani at Triveni, use of gelatins and poisons for fishing by other communities, and lack of moss, plankton and the essential flora deposition in the riverbeds for fish food. The fishermen opine that the industrial effluent has a major role in reducing the moss. The decreasing number of fish in the river streams can largely marginalize these underprivileged and predominantly illiterate tribes who hardly have any access to agricultural land and other alternative jobs. The availability of fish is declining, while the means of catching them, for example the supply of wood required for making fishing boats, has been restricted after the establishment of the National Park.

Water Conflicts

Conflicts are emerging between upstream and downstream water users, mainly between irrigation systems that draw water from the same stream. Some inter-sectoral conflicts are also observed although they are very few. For example, the Bhandara water supply system has started facing the problem of water shortage because of recent water diversions upstream of its intake. Victims of a 1993 flood are settled by its intake, about 2 kilometers downstream of Kusum Khola. They are accused of stealing water for irrigating their kitchen gardens and polluting water at the source. Conflicts have been so fierce that people have started thinking about removing the new settlers or shifting the intake further upstream.

Similarly, incidents of conflict have been reported, between the Machaan Hotel located near the Lothar river and irrigators of the Pratappur Mau Irrigation System, over the use of water during winter months in the East Rapti river. The hotel wants water to flow downstream for the use of boat services for tourists, whereas farmers want water for irrigating their crops.

Sand Mining

The riverbeds of the East Rapti river and its major tributaries have been good sources for sand, gravel and aggregates for construction in this rapidly urbanizing basin. As the quality of these materials in this basin is perceived to be superior, the rate of sand mining has been increasing over time. Furthermore, it has become a source of income for the District Development Committees as they levy a tax for sand mining. The collection of these materials, however, is not done in a regulated manner. Neither the individual collectors nor the licensed agencies are aware of, or serious about, the interests of other stakeholders. The haphazard digging of the riverbanks for collecting these materials has not only caused riverbank cuttings and landslides but also disturbed the river's flows causing, at some places, overflow of river water into agricultural fields, as floods during rainy seasons have raised riverbeds at some locations. The raised riverbed near Hetauda is perceived to be dangerous to the city itself. By the intake point of the Padampokhari Irrigation System, just about 2 kilometers downstream of Hetaunda, the riverbed is reportedly lowered. This has made it difficult and expensive to divert water to the permanent intake.

Increase in Cultivated Area

Over the last 20 years, the cultivated area in the basin has increased from 83,448 hectares to 85,578 hectares whereas the forest cover has decreased by 73,255 hectares indicating that part of the forest has been converted into agricultural lands.

Water Pollution

The pollution of water in the river basin due to disposal of industrial wastes, has been reported by the users and confirmed by the district officials. The brewery, soft-drink bottler, and paper mill are reported to have disposed of industrial waste into the river in the Chitwan district. The irrigation users of ward nos. 8 and 9 of the Birendranagar municipality in Chitwan have complained of the pollution in the irrigation water due to the waste disposal by the brewery and soft-drink industries. The people have lodged official complaints to the Ministry of Population and Environment (MOPE) and to the Ministry of Water Resources. The district officials said that this matter will be investigated. Likewise, people complained about waste disposal by the industries in the Hetauda industrial district in Makwapur. During the discussion, the Chief District Officer said that the industries have been asked to dispose of industrial waste after it is treated and they have agreed to do so. However, it remains to be seen whether they will comply with the decision reached between the local people, administration and the industries. The cases of water pollution are reported to the local authorities; however they lack the technical capability to investigate the matter and the MOPE does not have an office at district level. Therefore, the problems are not addressed immediately. The users in the river basin reported no other form of pollution. This is because most of the water in the river basin is used for irrigation.

Adverse activities, such as using poison and explosives for catching fish, harming the well-being of aquatic flora and fauna should be stopped. Safe disposal of industrial effluent should be sought. While this kills fish in the Rapti river it is also hazardous to wildlife in the Royal Chitwan National Park (RCNP).

In relation to water pollution, downstream stakeholders, particularly the livestock farmers, complain about the polluted water drained out of the industrial area of Hetauda where the number of industries (71 at present) is on the rise. Severe complaints and conflicts are not occurring, not because of unpolluted outflow, but because of the ignorance of downstream stakeholders about the degree of pollution and its adverse effects. Nevertheless, there is a growing concern about pollution and effects of polluted water on the life and property of the concerned people downstream. Because of this concern, perhaps, the government is planning to establish a Common Water Treatment Plant.

In the case of rural water-supply systems, the intake areas at the water source are protected through fencing against external pollution only in the immediate vicinity. The Hetauda industrial area and the Hetauda cement factory have polluted the Karra Khola that joins the East Rapti in Hetauda, and the East Rapti river itself, both in the Sandstone quarry site nearby Bhainse and from the effluent from the cement factory in Hetauda. The Hetauda industrial district is planning to minimize the pollutants from the industrial area.

Institutional Characteristics

District boundaries, traditionally and legally encompassing several village-development committees, form the main basis for state administration and governance. The hydrological boundary of the basin passes over two administrative districts. This indicates a need for a cross-district arrangement for managing river-basin water.

People in the basin have had a long tradition of making collective efforts to manage natural resources, including agricultural water. Traditionally, there have been several beneficiaries' organizations at the individual system level. They have been taking care of local operation and maintenance (O&M) activities through collective efforts. Going beyond that tradition, recently 134 irrigation systems in the Chitwan area were registered with the District Water Resources Development Committee. The registration provides them a legitimate status. In the past, farmer-managed irrigation systems of eastern Chitwan formed a separate federation for consolidating regional efforts to adopt a relevant irrigated agricultural development strategy, and accordingly approached the related agencies for assistance.

Historically, surface-irrigation systems were initially developed and managed by indigenous and tribal community organizations and the systems concentrated more in the central plains of the basin than in the hills. Later, with the state-supported resettlement programs in the basin area following disastrous floods and landslides in the surrounding hills, numerous immigrants received land entitlements on cleared forestlands in the basin. Irrigation development and management practices started becoming a concern of mixed communities. Presently, there are more than 200 farmer-managed irrigation systems in the basin and they account for about 90 percent of the irrigated area (RTDB/IAAS/IWMI 2000). The state initiated supporting irrigation developments in this area only from the 1960s.

Evolution and Use of Water Laws, Rules and Norms in ERRB

The District Water Resource Committees (DWRCs) in Chitwan and Makawanpur districts have been registering WUAs in their respective districts but the issuance of licenses to use water resources has not been put into operation. The DWRCs are not properly organized due to lack of budget and manpower. A workable mechanism for allocating, reallocating and monitoring uses of water resources is yet to be developed. The DWRC Chairman and the member secretary are not so aware of the existing and emerging issues in the basin and its subbasins. Scarcity of water and competition between water uses are increasing. District Irrigation Offices and District Water Supply and Sanitation Offices are facing increasing cases of the conflicts concerning different uses of water resources. Most of the conflicts are resolved at the local level by the users association or the concerned village development committee (VDC). District Irrigation and Water Supply Offices have resolved some of the disputes but there are a few conflicts that have reached the appellate court. The Jiudi-Chipleti Irrigation System in Chitwan is one example where conflicts were registered over sharing of water from the same river subbasin of Pampa Khola.

The Tharus and Darais were the original settlers in the Rapti basin area until 1953. They developed the irrigation systems before 1953. The need for irrigation water was less, as settlement in the area was very small and scattered. The villages contributed their resources for the development of irrigation according to their needs. With the implementation of the state-sponsored resettlement program since 1953, many people, mostly from western Nepal, have settled in the area after clearing the forest. Initially, they took management contracts from the irrigation systems developed by Tharus and Darais (Shukla et al. 1997). In course of time, they started the development of new irrigation systems.

An informal user group was formed to initiate the irrigation development. The users reported that in the beginning the distance between the headworks used to be 1.6 kilometers. The users developed the necessary rules with respect to the system development, resource mobilization, water allocation and distribution, and O&M. These informal rules constituted the working rules for the operation of the system.

With the development of new irrigation systems there was a rise in conflict among the users, which required appropriate mechanisms for resolving the disputes. Another reason for the conflicts was due to the change in the watercourse by the river during high flood, which washed away the intake and required construction of a new intake at a different location. However, earlier appropriation rights were recognized. The mechanism adopted by the users to solve the disputes and in defining the water rights was through negotiation among the users. Therefore, the downstream users have to negotiate with the upstream users if there is objection from them. However, there is an understanding between the users that the need of every user should be addressed as far as practicable.

In some cases, government functionaries at the local, district and zonal level arbitrate conflicts, and a written agreement is signed between the disputing parties (Shukla et al. 1997). Such agreements served as a basis for rules and norms for the development and management of irrigation systems. The development of rules and norms was further reinforced when the government started various intervention programs to support the development and rehabilitation of irrigation systems. One of the conditions for government interventions was the requirement for official registration with a water user association (WUA). Consequently, the informal water user groups became WUAs and their informal rules were formalized through the WUA constitutions. The users reported that almost all the WUAs in the river basin are legally registered, as they received government support. The water laws and rules, as practiced in the river basin at present, evolved through various negotiation processes between the users as the history of irrigation development took place since 1953. The formalization of these rules however took place when external support was provided to these irrigation systems.

The Water Resources Act (WRA) of 1992, replacing canal, electricity and related water resources acts of 1967, dealt mainly with the concept of public domain in water, a system of licensing and the authority to charge fees for services rendered. This Act was the first comprehensive treatment on the management of water resources in the country. The new Act has provided the ownership of water to the state irrespective of its origin or existence. This is a major departure from the earlier concept of private ownership of water as provided for in the Aquatic Animals Protection Act, 1960. The WRA is an important legal instrument to give absolute recognition to the state's ownership and control of water resources. The government is empowered to allocate water rights and resolve related issues, and to license and control usage. Licenses are mandatory for commercial and industrial users, and these licenses are transferable.

The prior use or the established water use of riparian owners under the provisions of the National Code have also been continued and protected by the WRA. These prior rights did not limit the quantity of water they were entitled to use. The traditional use of water did not anticipate shortages in water supply and hence, did not foresee the need to set priorities among water users. Readjustment in traditional water uses and inclusion of new members have been possible in practice through government intervention by expanding the command area with additional investment for permanent structures.

Land Rights and Water Rights

The WUAs represent the collective interest of the respective users in the basin. In the absence of male members, women can also represent the male members in WUAs or assembly and related decision-making processes as de facto members (Ghimire et al. 2000).

In general, access to irrigation water rights is tied up with access to land rights. In irrigated lands, this means that the rights to use water are automatically transferred to the offspring as landownership is inherited. A similar case prevails when land buyers acquire landownership after purchase. Water rights are also related to the tenure system. Different kinds of tenure arrangements operate in the basin, e. g., owner-operator, share-cropping, mortgage, lease, and contract farming. Share-cropping is a quite common practice, after owner-operators. All operators hold possessions of water rights as they are required to contribute resources in terms of kind, cash or labor for the system development, acquisition, distribution and the use of water resources for irrigation.

To sum up, the prevailing practices of customary rights in the river basin are: water share based on investment, water right purchase from others (Pradhan 1989) and water rights proportionate to the land in irrigated area (Pradhan 1989). The availability of irrigation water for area expansion, the users' willingness to invest in its development, and external resources obtained for the development of the irrigation have influence in defining the water right of the users in the river basin.

Dispute Management

The intersystem conflict is mainly between agricultural use versus the National Park, hotels and tourist resorts due to the many diversion structures in the river, which obstruct boating by tourists who are the guests of several hotels and resorts. The consumption of water by several irrigation systems, especially towards the upper section of the National Park, has seriously decreased the amount of water in the river during the summer season.

External factors have been a potential cause of conflicts between systems, particularly high floods (associated with catchment degradation due to encroachment upstream) that damage diversions structures and change stream-courses. In some cases, intervention by external agencies has displaced the old structures and obstructed water-distribution patterns among users. Thus, construction of new intakes invites conflict when existing intake points and canal lining are lost, as none of the users want to lose their claim to water. Conflicts also occur due to those who have sometimes not participated in, or not paid cash or required labor for, repair-works. Although settled by the users themselves, more conflicts do occur due to water competition in water-deficit areas.

Depending upon the nature and severity of conflict, a range of mechanisms is used to resolve conflicts. These include both formal and informal mechanisms. Although not frequent, there are cases resolved by simple informal negotiations and arbitration, for example where an agreement has been signed between the disputing parties through the mediation of the village development committee (VDC) and local *Panchabhaladmi* (group of local people accepted by the disputing parties). In some other cases, the VDCs have forwarded the cases to the Chief District Officer (CDO). Although informal mechanisms are most common, users approach legal and quasi-legal institutions when informal mechanisms fail to resolve conflicts adequately (Shukla et al. 1997). Some of the cases have passed from the District Court even up to the Supreme Court for final resolution of the problems (Shukla et al. 1997). Different water rotation schedules are used to minimize conflicts within the system. Therefore, the conflict between and within irrigation systems is less pronounced in the river-basin area.

There was conflict between supply of drinking water of Pithuwa VDC and irrigation water of neighboring Chainpur VDC, as both have the same water source on the Kair stream. It is natural that both desire water supply according to their own convenience. Since drinking water is a more critical issue than irrigation and due to high water demand during daytime, the conflict was resolved by a mutual written agreement whereby Chainpur would divert water only at night for irrigation so that the high demand for drinking water of Pithuwa residents is met during daytime.

Inter-Sectoral Water Transfer and Organizational Linkages

Important actors for managing the catchment area at the national level have been identified as the Ministry of Water Resources (MOWR) and the National Planning Commission (NPC), whereas at the district level, actors include Forestry, Water Supply and Sewerage, District Development Committee, Electricity, Irrigation Offices and concerned municipalities. Resource users, both as individuals and organizations, VDCs and industries are responsible for managing the catchment area at the local level. The Makawanpur industrial district is the authority to manage water in the Makwanpur district. A brief review of the water uses in the ERRB and its legal status is presented in table 1.

Precise policies are lacking with respect to inter-sectoral water transfers or interbasin transfers of water. The natural resources in the country are owned by the state and only use rights are given out. According to those principles, the central government level agencies have had the sole decision-making authority. Recently, initiatives have been made for delegating some authority to district-level water-resources committees. Subsequently, these district- level committees are expected to be primarily involved in river-water management tasks at the district level.

There are no institutional arrangements at the Rapti basin level to cope with multiple use of water. For inter-sectoral water allocation, only informal arrangements exist, for example, between water mills and irrigation. The same is the case for intra-sectoral water allocation and distribution, e.g., between irrigation and irrigation. However, a district-level federation of WUAs in both districts (Chitwan and Makawanpur) covering the East Rapti basin, and a separate federation of WUAs in East Chitwan, have recently been formed.

Table 1. Water utilities in the East Rapti river basin.

Type of utility	Number	Who owns utility	Who operates utility	Legal status of operator
Surface irrigation systems	214	Government and farmers both collectively and individually	WUAs = 208; jointly by the government and farmers - 6	Govt. Department, local WUAs; some recognized by law and some informal
Groundwater schemes	STW = 589 Dug-wells = 1,809 Treadle pumps = 47	Mostly by individual farmers and some in groups	Mostly by individual farmers and some in groups	Some recognized by law and some informal
Domestic water supply schemes	45	Municipality-level schemes (3 schemes) by the government and village-level schemes by users' groups	Municipality-level schemes by Water Supply Corporation and village-level schemes by users' groups	Majority of user groups legally recognized
Hydropower plants	One	The government	Nepal Electricity Authority	Government body
Wastewater treatment plants	None	Not applicable	Not applicable	Not applicable
Wetlands and other water bodies	Numerous; exact number yet to be ascertained	Royal Chitwan National Park	Park officials and local people in buffer zone	Buffer zone peoples' committees legally recognized
Hand pumps	Numerous; exact number not available	Individual farmers	Individual farmers	Informal and private
Industries	126	Public and private	Government and private sectors	Legally recognized

Customary Practices for Inter-Sectoral Water Allocation and Distribution

Except Narayani Lift and Khageri irrigation systems, which are jointly managed by the government and users associations, farmers themselves manage all other systems. Typically, irrigation systems acquire water from a series of headworks along a stream. An arrangement for water allocation between these systems is based primarily on mutual consensus among upstream and downstream users, especially during the dry season. The tradition is that the downstream systems approach the upstream system through functionaries to make an informal request for sharing water. Also, there are systems among which a formal legal right of access to water is also found. In some others, water is allocated proportionately into a number of shares depending upon the labor contribution to O&M to maintain the common intake.

In the case of an intra-system water allocation, boundary rules are used to define who are users and who are not. Each farmer within the rule is allocated water based on his labor contribution to O&M of the system. Stringent rules are implemented during water-deficit periods to ensure equity in allocation. Systems switch from a continuous mode of supply to a rotational pattern of water distribution method as canal supply decreases towards the lean season. In most of the systems, opportunistic users' behaviors like shirking work and water pilferage are controlled by payoff rules for graduated sanctions.

One embankment (18 km long) and a number of spurs are built along the river course for flood protection in the downstream area. But no storage facility that can control or distribute the flow of units from the river to other places or sectors is developed. No explicit allocation of uncontrolled river water is found among various sectors. As mentioned earlier, conflicts between tourism and irrigation sectors indicated that although the national government assigns a high priority to tourism and national parks, exclusion of water use from the river for irrigation appears impossible unless options are developed acceptable to both sectors. This brings an issue of little or no water allocation across sectors and protection of riparian property rights.

All but one of the industries is supplied with water from the Hetauda industrial district. Using an intake channel, they extract water from both the Karra stream and a well. Hetauda Textiles has its own well and only a minor part of the consumption is supplied by the Hetauda industrial district. Water allocation and supply within industries are demand-based and do not seem to be a problem since revenue is collected from the use of power.

Integration of Overall Legal Framework with Water Law

There are some incongruities of laws related to water resources. Laws relating to a specific subject matter and to a particular area supercede the laws relating to water resources. For example, the 1998 Drinking Water Regulation, prescribed in pursuance of Section 24 of the 1992 WRA, provides a set of separate and contradictory procedures from that prescribed in the 1993 Water Resources Regulation with regard to licensing, and fees to be charged for a license, and for constitutions of user's associations, dispute settlement mechanisms and a tariff-fixing committee.

The 1999 Irrigation Regulations, which were also prepared based on the 1992 WRA, prescribe a separate set of rules and procedures with regard to forming WUAs. This regulation prescribes authority to the District Irrigation Officers (DIO) to constitute WUAs for those systems that are to be handed over to FMIS. The 1998 Local Self-Governance Act (LSGA) has given similar authority to the VDCs and municipalities for development and management of drinking-water facilities, irrigation canals and hydropower projects. The VDCs, DDC, and municipalities have the authority to levy taxes for using natural resources within their jurisdiction.

The 1998 LSGA requires the local entities to form users' associations or consumer's groups for implementation of village-, municipal-, and district-level development projects. But it does not have an independent authority to register water user's associations. The 1999 Local Agencies Regulation, under the 1998 LSGA, has prescribed rights and responsibilities of users' groups, and procedures for engaging the services of users' groups for the construction of development projects.

Specific enactments, such as the 1967 Forest Conservation Act, 1972 National Park and Wildlife Conservation Act, and 1972 Soil and Watershed Conservation Act, restrict certain activities on rivers, streams or other similar sources of water within their respective jurisdictions. In these cases, the rights of the people are subject to the provisions of such enactments.

Review of legislation related to water-resources development reveals overlaps and conflicts between different acts, and between the act and regulations under the acts. There is no legislation regarding inter-sectoral water allocation and distribution, and interbasin transfers. There should be harmony among related legislations.

Water Administration

As a major natural resources, water should be developed and managed so that it will play a catalytic role for the social and economic development of the country. Because of the temporal and spatial variations and the resultant scarcity value of the resource, there exists one school of thought of recognizing and treating it as an economic good, while on the other hand, it is also required to manage a certain amount of balance between the social and the economic good. Consequently, appropriate institutions are required to be developed at national, regional, basin, district and local levels for managing the water resources of the country.

Water availability in Nepal is characterized by a highly unbalanced situation between availability and the need. There is asymmetry between the supply and demand and this has put a tremendous amount of pressure on the government capacity for the management of the resource. Water-management elements such as demand management and water-use efficiency along with crop diversification have been lacking in the planning of water resources.

The development and management of water resources are patterned along the lines of sub-sectoral uses. Irrigation, domestic water supply, and generation of power have been entrusted to separate departments, and sometimes put under different ministries resulting in a piecemeal approach. There has been an absence of effort to create, or a failure to see the need for, an appropriate institutional framework or mechanism to give effect to the policy on the utilization of water resources on a river-basin basis. Water administration continues to move along traditional and sectoral lines. The Ninth Plan has put an emphasis on the integrated development of water resources on the basis of river basins.

A review of the policy framework for the management of irrigation, domestic water supply, and hydropower sub-sectors, together with a recent initiative to empower local bodies with responsibility and resources, reveal a definite shift towards community participation in service delivery and a great reliance on the private sector for the production of goods and services.

Over the years, water-resources management has gone through a series of changes. Before the Sixth Plan period, the responsibility for development and management for meeting water demand was vested with a number of central government departments and their supervisory ministries. This approach manifested a lack of participation by beneficiaries and the system performed dismally. The government could not sustain the level of financial resources needed to operate, maintain and manage the structures in addition to finding funding sources for new projects. In the circumstances, new development efforts came to be based more and more on community and private-sector participation.

A number of central-level institutions are involved in formulating policy, plans and programs for the development and management of water resources. The ministries and their departments related to water-resources development are responsible for formulation of policies, implementation of plans and programs, and monitoring and evaluation in their respective sub-sectors. There is an absence of a long-term and comprehensive vision for development of water resources. There are good sub-sectoral plans but they lack cohesion and coordination. Sub-sectoral agencies for irrigation, domestic water supply, and hydropower formulate policies and regulations based only on their limited sub-sectoral needs. Uncoordinated development of water resources, coupled with pressure from increasing population and decreasing sources of water have resulted in adverse impacts on the ecological systems. Conflicts among users are emerging. Lowering of groundwater levels, drying up of wells in certain locations, destruction of forests, and pollution of rivers from towns and industrial effluents are some of the examples.

Separation of functions between the ministry, department and district offices or operational-level agencies tends to get blurred in practice. Interference in implementation from politicians and higher-level officers is common. The tendency of referring to a higher-level office for decision or for instruction on matters within one's own jurisdiction and authority is also widely practiced. Involvement of a policy-level body in regulation makes policy implementation weak, and regulation ineffective. Under the current framework, overlapping in the functions is evident from information in table 1. There is an absence of clear separation of policy from implementation or operational functions.

Spatial water administration is based on administrative boundaries of districts that do not follow the basin's hydrological boundaries. There are various bodies for coordinating various agencies involved in programs associated with water resources. The Water Resources Development Council, National Planning Commission and District Water Resources Committees are the main agencies associated with the inter-agency coordination. There are no established procedures for the involvement of the private sector in the irrigation activities and licensing, and pricing arrangements are still under discussion.

Conclusions

The ERRB is an open basin and has both traditional and modern methods for water use for various purposes. However, there are seasonal and temporal variations in water availability across the basin. The users have been following both customary practices and legal provisions as specified in the WRA to regulate the use of water in the basin. However, present legislation is not sufficient. The creation of new basin-level institutions and regulatory frameworks is required for water allocation and sharing; private sector and community participation; strengthening of the regulatory system for water rights, pollution control and environmental management; water pricing and cost recovery; and groundwater management.

Lack of specific water rights and ownership issues need to be resolved. Historically, water has been allocated mostly for irrigation benefits. With the enactment of the 1992 Water Resources Act, the government is now empowered to allocate water rights, resolve water-related issues and license and control usage. The 1993 water-resources regulation provided for the formation of users' organizations, establishment of district water-resources committees, licensing, and the formation of committees for resolving disputes, but all of these have yet to be enforced or implemented properly.

Another issue of major concern is the lack of harmony among the related laws. The 1992 Water Resources Act is a comprehensive piece of legislation on water resources dealing with their development, utilization and conservation. A review of other laws related to water resources shows a certain amount of incongruity. The Drinking Water Regulation (No. 2055) for instance, has prescribed a set of separate and contradictory procedures with regard to licensing, constitution of users' groups, dispute settlement and committee for fixing tariff. Likewise, the Irrigation Regulation (No. 2056 of 2000) has prescribed a separate set of rules and procedures regarding the formation of users' associations. The authority for the same is entrusted to the District Irrigation Officer, whereas the Local Self-Government Act (No. 2055 of 1999) has given similar authority to the VDCs, municipalities and DDCs.

The preferable option would be the consolidation of the 1993 Water Resources Regulation with all conflicting procedural laws found in various regulations relating to licensing fees, registration of WUAs and WUGs, irrigation and drinking water service fees, and dispute settlement mechanisms. While doing so, it is necessary to amend the Irrigation Regulation (No. 2056) so as to make District Water Resources Committees responsible for registration of WUAs. Likewise, LSGA and Regulations also need additional provisions under which DDCs, VDCs, and municipalities are also required to obtain licenses for proposed and planned drinking water and irrigation projects, leaving service delivery and implementation functions to them.

Although statutory laws have been promulgated and amended over the last 30 years, many of the water-rights-related activities in the water sector are still based on customary rights. As Nepal's population grows, water stresses will be felt frequently and conflict on water use will also be more frequent. Also, since water-resources development is an integral part of national economic growth, there will be new investments in infrastructure that will require trade-offs and/or compensation to existing users. This means the legal framework for water use in Nepal must address these emerging issues. It must be able to facilitate a transition from customary rights to statutory rights. In addition to the legal framework, there must be an improvement in the enforcement of statutory laws and regulations.

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Innovation in Property Rights and Groundwater Irrigation Management: A Case Study of Tube-Well Ownership in Hebei, China

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Abstract

Traditionally, water problems have been treated mainly as engineering and technical problems. However, increasing evidence shows that water management and institutional arrangements are important measures for dealing with water-shortage problems. The purpose of this paper is to provide a better understanding of tube-well ownership innovation and groundwater-irrigation management in the Hebei Province of China. Econometric models for testing the determinants of tube-well ownership innovation are developed and estimated using several unique sets of data from 30 randomly selected villages within 3 counties of the Hebei Province. The results show that since 1980 collectively owned tube wells have been gradually replaced by a more market-oriented type of privately (or quasi-privately) owned tube wells. The major determinants of this innovation in tube-well ownership within the irrigation system are: increasing water shortage problems; stresses from local population growth combined with declining land endowment; the weakening of village or community economic power; improved human capital of the community; market development; and water finance and credit policies. Based on the findings of this study, a number of policy recommendations are made for future reform of the agricultural groundwater irrigation system in China. The authors propose that the government should encourage tube-well ownership innovation by effective water finance and credit policy instruments. Sustainable development of water resources, combined with rational water pricing should be promoted, so that tube-well ownership innovation should be emphasized by future water policies.

Background

Faced with increasingly competitive demands for water from a rapidly growing industrial sector, an expanding area under irrigation and a wealthier and growing population, global society has

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turned increasing attention towards the resolution of water-scarcity problems. Severe water shortages have also become major constraints to the sustainability of China's social and economic development. Although China ranks sixth in the world in total water-resources endowment, on a per capita basis it is among the poorest, having only one-fourth of the average world level (Liu and He 1996). Furthermore, its water resources are overwhelmingly concentrated in southern China, while northern China, an important agricultural region and the location for much of China's industrial production, has a far lower per capita water endowment. The national shares of population and cultivated area in Northern China were 52 percent and 70 percent, respectively, but only 24 percent of the nation's water resources were allocated to the region in 1998 (State Statistical Bureau 1999; Ministry of Water Resources 1998). Economic and social development in northern China have been due, partly, to easily exploitable groundwater (Ministry of Water Resources 1998).

Traditionally, water problems have been mainly treated as engineering and technical problems. However, increasing evidence shows that water management and its institutional arrangements are important measures for dealing with water-shortage problems (World Bank 1993; Johnson et al. 1995). Since the 1980s, many developing countries, along with some developed countries, have begun to transfer irrigation management responsibilities from the government to farmers' organization or other private organizations, in order to mitigate the financial burden of water projects, as well as to improve the efficiency of water use and supply (Vermillion 1997).

With rural reform and the implementation of production responsibility in China, agricultural-production management was transferred from the collective to farm households, which resulted in incompatibilities between collectively owned irrigation systems and privatized agricultural production. The increasingly serious aging and deterioration of rural water projects, due to incompatibilities between collective small-scale water project management and farm household agricultural-production management have become an important constraint to rural economic dvelopment (Chen and Yang 1998). To meet the goals of agricultural development, property rights innovation within small rural water projects has been initiated and developed since the early 1980s.

Different property rights regimes within irrigation systems have different impacts on water project management efficiency (Wang et al. 2000) and cropping patterns (Xiang and Huang 2000). In seeking to gain a clear understanding of property rights innovation within an irrigation system, two critical questions arise: how have the property rights of an irrigation system changed under innovation and what are the determinants of property rights innovation? How do we reform policies relevant to irrigation in order to promote rational property rights innovation within an irrigation system? Although understanding property rights innovation has important policy implications, almost no empirical study on this issue has been done in China.

Based on the water source, an irrigation system can be classified into either a surface-water irrigation system or a groundwater irrigation system (GWIS). Considering the increasingly important role of groundwater irrigation systems (mainly tube wells) in agricultural production (especially in northern China), the purpose of this paper is to understand ownership innovation within tube-well irrigation systems (or more simply referred to as tube wells), to understand the determinants and impact of innovation, and to provide empirical evidence for rational irrigation policy reform.

Tube-Well Ownership Innovation and Its Influential Factors

Literature Review and Data Sources

Among all the influential factors driving institutional innovation, relative price changes resulting from changes of natural-resources endowments and population increase are those emphasized by economists (North 1990; Demsetz 1969). Schultz (1968) found that the rise in the economic value of a human being is the main reason for institutional innovation. Government policies, the degree of democratic governance, the state of the rural financial market, the degree of agriculture commercialization, social mores, the regulation of inheritance and the legal constraints on property rights are all important factors of institutional innovation (White 1995). After synthesizing most research findings, Otsuka (1995) summed up five factors that influence tube-well ownership innovation: natural environment, population pressure, policy, commercialization and social environment. Some research such as that by Qiao et al. (1998) and Otsuka (1995) have all corroborated their empirical findings with theory, when they conducted their research on forestry and land property rights innovation.

Will tube-well ownership innovation also adhere to theory? Will the innovation affect cropping patterns? In order to answer these question, we randomly selected 30 villages from three counties (Yuanshi County, Feixiang County, and Qinglong County) in the Hebei Province to conduct a field survey. Located in the Haihe river basin, Hebei is not only a water-scarce province, given that per capita water availability is only one-sixth of the national level, but is also an important agricultural production base for the country, where over 70 percent of irrigation water comes from groundwater. These three counties are all facing very serious water scarcity and have tube-well ownership as the predominant pattern of water use. The extent of tube-well ownership innovation and the cropping patterns that exist are very representative of those within Hebei, as well as within the whole of China itself. The field survey of these 30 villages covered four periods: the initial year of the production responsibility system (about 1983), 1990, 1997 and 1998.

Definition of Tube-Well Ownership

A tube-well irrigation system is defined as a system of water-extraction facilities used for supplying groundwater irrigation. An operational unit of the groundwater irrigation system comprises one complete set of water-extraction facilities, which include one tube well and other attached units such as pump(s), electricity supply and other necessary facilities. If the village collectively owns the tube well, we define it as collective ownership; otherwise, it is defined as non-collective ownership. Collective tube-well ownership is also further classified into the categories of pure-collective and quasi-collective ownership. If the collective owns all the facilities (including the tube well and its attached facilities), then we call it pure-collective ownership; if, except for the tube well, all the other facilities are owned by farmers or other organizations, such ownership is considered to be quasi-collective. For non-collective ownership of tube wells, there are also two patterns: one being private ownership and the other shareholding ownership. If all facilities belong to one owner, then it is defined as private ownership; otherwise it will be defined as shareholding ownership, which means that several shareholders will own the tube well at the same time.

Sample Description

Table 1 summarizes some general characteristics of the sample counties. Relatively large differences in per capita cultivated area, average groundwater table levels and shares of irrigated area existed in these counties; but they all present similar general development trends. Since the 1980s, per capita cultivated area has continuously declined and water resources have become increasingly scarce. Furthermore, as the groundwater table has dropped, the share of surface water used in irrigation has decreased. Groundwater has become the crucial source of irrigation water source. By 1998, the share of groundwater use had reached 100 percent, in both Yuanshi and Feixiang counties.

Survey data also indicate that since the 1980s, the share of sown cropping area under grain crops in the three counties has exhibited an increasing trend, the major grain crops being wheat and maize. Except for Qinglong County, the total shares of crop area sown with wheat and maize in the other two counties are very high (being generally higher than 80%), and had reached 55 percent in 1998. The share of sown area under cash crops in Qinglong County has increased constantly while that under cash crops in Yuanshi and Feixiang counties has declined (especially after the 1990s). No cotton has been planted in Qinglong County, whereas cotton is the main cash crop in the other two counties. The decline in the share of sown area under cotton is largely behind the decline of sown area under cash crops in Yuanshi and Feixiang counties (table 2).

Investment in Tube Wells

Tube wells were mainly financed by the local villages and townships, with government subsidies (to varying extents) up until implementation of the Household Production Responsibility System (HRS) that was initiated in the late 1970s. Farmers had always contributed family labor towards the construction of tube wells. Collective ownership dominated all forms of ownership throughout the groundwater irrigation system. With the implementation of HRS, there has been a declining role for the collective in the local economy, and a growing involvement of private individuals (farmers) in groundwater irrigation. The investment from collectives and the government has dropped considerably, while investment by farmers has increased significantly since the early 1980s. The shares of collective and government investment in groundwater irrigation declined from 21 percent and 12 percent, respectively, in 1983 to 5 percent and 3 percent, respectively, in 1998. Meanwhile, the share of farmers' investment had increased from 67 percent in 1983 to 92 percent in 1998 (table 3).

Characteristics of Tube-Well Ownership Innovation

The most significant change in the tube-well ownership regime within the irrigation systems in our study area, is the shift from collective to non-collective forms of ownership. In the early 1980s, the collectively owned groundwater irrigation system accounted for 83 percent of all groundwater irrigation (table 4). This was reduced to 31 percent in 1998. The share belonging to non-collectively owned irrigation systems increased from 17 percent to 69 percent, during the same period. Tube-well ownership innovation in the three counties has been uneven. Innovation in Feixiang County has been the quickest, since its share of non-collective tube-

Table 1. General situation in the sample site.

	Cultivated area (1,000 ha)	Share of irrigated area (%)	Per capita cultivated area (ha/person)	Share of surface water use in irrigation (%)	Share of non-collective tube-well ownership of GWIS (%)
Qinglong County					
1983	1.05	13	0.07	29	0
1990	0.98	15	0.06	31	4
Average in 1997-1998	0.93	42	0.06	6	69
Yuanshi County					
1983*	2.02	94	0.11	7	28
1990	1.92	95	0.10	15	48
Average in 1997-1998	1.81	95	0.08	0	63
Feixiang County					
1983	1.62	61	0.15	0	9
1990	1.53	69	0.13	1	54
Average in 1997-1998	1.50	83	0.12	0	80

Data source: Authors' field survey in 30 randomly selected villages from 3 selected counties of the Hebei Province.

Table 2. Cropping pattern changes in three sample counties.

	Total sown area ('000 ha)	Share of sown area of grain crops (%)			Share of sown area of cash crops (%)		
		Sum	Wheat and maize	Others	Sum	Cotton	Others
Qinglong County							
About 1983	1.10	99	38	61	1	0	1
1990	1.08	98	41	57	2	0	2
Average in 1997-1998	1.13	95	55	40	5	0	5
Yuanshi County							
About 1983	3.47	87	84	3	13	7	6
1990	3.41	88	86	2	12	7	5
Average in 1997-1998	3.37	93	91	2	7	3	4
Feixiang County							
About 1983	2.38	73	66	8	27	23	4
1990	2.39	78	72	6	22	19	3
Average in 1997-1998	2.50	93	85	8	7	3	4

Note: Cash crops include cotton, oil-bearing crops, vegetables, etc.
Source: See table 1.

Table 3. Groundwater irrigation investment in the 30 sample villages in Feixiang, Yuanshi and Qinglong counties, Hebei Province.

		Sources of groundwater irrigation investment (%)			
Year	Total	State	Collective	Farmers	Others
1983	100	21	12	67	0
1990	100	10	11	69	11
1998	100	3	5	92	0

Source: Authors' surveys in randomly selected 30 villages from 3 selected counties of Hebei Province.

Table 4. Changing structure (%) of tube-well ownership, 1983-98.

Year	Collective vs. non-collective		Within collective		Within non-collective	
	Collective	Non-collective	Pure	Quasi	Shareholding	Private
1983	83	17	52	48	100	0
1990	56	44	24	76	99	1
1997	32	68	16	84	87	13
1998	31	69	18	82	86	14

Source: See table 1.

well ownership has increased by 71 percent from 1983 to 1998; the share of Qinglong County increased by 69 percent while that in Yuanshi County increased by 35 percent in the same period (table 1).

Within the collective tube-well ownership system, pure collectively owned irrigation schemes have been gradually replaced by quasi-collective ownership (table 4). The share of quasi-collective ownership accounted for only 48 percent of the GWIS under collective ownership in 1983. This share rose to 82 percent in 1998, and dominated the collectively owned irrigation system. On the other hand, the share of pure collective ownership within the collectively owned irrigation system declined from 52 percent to 18 percent during the same period (table 4).

The non-collectively owned groundwater irrigation systems were dominated by farmer-shareholding in the initial stage of tube-well ownership change, due to the credit constraints faced by individual farmers. But the individual privately owned irrigation system has been growing rapidly since the early 1990s, and increased from only 1 percent in 1990 to 14 percent in 1998 (table 4).

Factors Correlated with Innovation in Tube-Well Ownership

This section reviews factors that are correlated with changes in tube-well ownership institutions. The next section uses an econometric model to further explore determinants of innovation in tube-well ownership.

Water Scarcity

The groundwater table is an important indicator for water resource scarcity, given that decline in the groundwater table usually means increasing water scarcity. According to a group analysis of the share of non-collective property rights, general trends show that the share of collective tube-well ownership within the GWIS will decline, and the share of collective ownership rise, with the lowering of the groundwater table (table 5). It implies that increasing water scarcity will induce the innovation of tube-well ownership and this conforms to our expectations. Table 5 also shows that since the 1980s, the groundwater table has dropped annually and that the drop rate has accelerated during those years.

The share of surface water use indicates the degree of exploitation of groundwater. If the share of surface water use is low, then the share of groundwater use will be high; this means that the degree of groundwater exploitation is large, and also implies increasing water scarcity. Since the 1980s, the share of surface-water use has decreased from 12 percent of the total water use in the early 1980s to 2 percent in 1998. Agricultural development depends more and more on groundwater, which has become the main source of water for meeting local irrigation demand (table 5). With the ratio of surface water to total water use in decline, the possibility of non-collective tube-well ownership innovation within the GWIS will increase.

Table 5. Relationship between tube-well ownership innovation and water-resources scarcity.

Grouped in share of non-collective tube-well ownership (%)	Average share of non-collective tube-well ownership (%)	Average groundwater table in the last year (meter)	Share of surface water use (%)	Year	Average share of non-collective tube-well ownership (%)	Average groundwater table in the last year (meter)	Share of surface water use (%)
0	0	42	16	1983	17	37	12
1-50	30	43	3	1990	44	42	16
51-99	77	40	1	1997	68	47	2
100	100	53	2	1998	69	48	2

Note: Groundwater table is defined as the distance between available water and the earth's surface; share of non-collective tube-well ownership is defined as the ratio of the number of non-collective tube wells to the total number of tube wells; share of surface water use is defined as the ratio of surface water use to the total irrigation water use. Sample distribution in the four groups is 53,16,25,26.

Source: See table 1.

Income

In our survey, we used per capita net income of farmers and per capita income of collectives to indicate the economic well-being of the local community. Survey findings indicate that, this the rise of per capita net income of farmers, the share of non-collective tube-well ownership has also shown a tendency to increase (table 6). However, we need to further understand the relationship between per capita net income of farmers and non-collective tube-well ownership innovation, since the per capita net income of farmers will be influenced by time variables.

Compared with the 4.41 percent annual growth rate of farmers' net income, collective per capita income has displayed a declining trend up to the mid-1990s, when per capita income of the collectives had begun to increase (table 6). With the decrease of per capita income of the collectives, however, the share of non-collective tube-well ownership has increased. This indicates that the decline of collective economic power may be one of the reasons behind tube-well ownership innovation.

Human Capital and Environmental Stresses

Human capital is a comprehensive indicator of a person's intellectual, mental and management ability. Among all the factors that comprise human capital, education level is the most important index. Therefore, we select the share of labor with middle-school-level and higher education as a representative indicator of human capital. Table 7 shows that there exists a positive correlation between tube-well ownership innovation and human capital improvement.

Per capita cultivated area indicates the degree of environmental stress. Large per capita cultivated area implies small environmental pressures, whereas a small cultivated area per capita will indicate that there are large environmental pressures. According to the grouped data in table 7, there does not exist an obvious correlation between tube-well ownership innovation and per capita cultivated area. However, table 7 also shows that since the 1980s, the per capita cultivated area in 30 villages has decreased and the share of non-collective tube-well ownership has shown an increasing trend. Therefore, further research needs to be conducted to ascertain if there are any relationships between tube-well ownership innovation and environmental pressures.

Policy Factors and Market Development

Tube-well ownership innovation has occurred and increased under specific policy environments. Two principal policies that are closely related to expenditures on the groundwater irrigation system are policies for financial subsidies and policies for credit. There are some differences in service objectives between these two policies. The village collectives can obtain financial subsidies for water-related expenditures, while farmers can also obtain them directly. However, for water-credit policy, village collectives have more opportunities to obtain credit than do farmers. Based on this, we expect that the water-finance policy will promote tube-well ownership innovation, whereas the water-credit policy will hinder tube-well ownership innovation.

Survey results show that since the 1980s, the share of villages that can obtain water credit has not changed much, being about 50 percent, whereas the share of villages that can obtain water-finance subsidies has increased annually, from 6 percent in 1998 to 47 percent in 1998 (table 8). Group analysis also indicates the complex relationship between tube-well

Table 6. Relationship between tube-well ownership innovation and economic power of local community.

Grouped in share or non-collective tube-well ownership (%)	Average share of non-collective tube-well ownership (%)	Per-capita net income of farmers (yuan/year)	Per-capita income of collective (yuan/year)	Year	Average share of non-collective tube-well ownership (%)	Per-capita net income of farmers (yuan/year)	Per-capita income of collective (yuan/year)
0	0	705	39	1983	17	498	40
1-50	30	811	23	1990	44	778	28
51-99	77	788	19	1997	68	901	36
100	100	914	21	1998	69	951	38

Note: Per-capita net income of farmers and per capita income of collective are calculated in real price of 1990.
Source: See table 1.

Table 7. Relationship between tube-well ownership innovation, human capital, and environmental stresses.

Grouped in share of non-collective tube-well ownership (%)	Average share of non-collective tube-well ownership (%)	Share of middle school educated labor (%)	Per capita cultivated area (ha)	Year	Average share of non-collective tube-well ownership (%)	Share of middle-school educated labor (%)	Per capita cultivated area (ha)
0	0	39	0.10	1983	17	31	0.11
1-50	30	42	0.11	1990	44	44	0.09
51-99	77	51	0.10	1997	68	51	0.08
100	100	51	0.10	1998	69	51	0.08

Source: See table 1.

ownership innovation and both water-finance policy and water-credit policy. From the general development trend, the larger the number of villages that can obtain water finance subsidies, the greater the possibility of tube-well ownership innovation; and the fewer the number of villages that can get water credit, the greater the possibility of tube-well ownership innovation; which conforms to our expectations.

A higher degree of development and convenience of transport implies the existence of a more developed market, with a higher degree of commercialization and information content. Since the 1980s, the transportation conditions in these 30 villages have been improved gradually, so that 77 percent of villages had roads in 1998 (table 8). According to group analysis, based on the share of non-collective property rights, general development trends show that the share of non-collective tube-well ownership will increase with the improvement of transportation conditions. Therefore, market development may be one of the important factors that influence tube-well ownership innovation.

In summary, tube-well ownership innovation within the GWIS may be the outcome of factors that include: an increasing shortage of water; an increasing level of groundwater exploitation; a weakening of collective economic power; increasing environmental pressures within local communities; improvements in human capital; market development; and both water finance and credit policy.

Econometric Model of Tube-Well Ownership Innovation

In order to further explore the correlation between these phenomena, and to move beyond the simple single-factor analysis, we have constructed an econometric model of tube-well ownership innovation determinants to conduct a multi-factor analysis for tube-well ownership innovation.

Specification of Econometric Model of Tube-Well Ownership Innovation Determinants

Based on the above discussion, we propose the following empirical model to analyze the determinants of tube-well ownership innovation:

1) $Private_{jt} = F(Wtable_{jt-1}, Wsource_{jt}, Land_{jt}, Income_{jt}, Revenue_{jt}, Edu_{jt}, Finance_{jt}, Credit_{jt}, Road_{jt}, Dv_j, Dy_t) + e_{jt}$

- In the above equation, j represents a village, t the year and e the random error vector.
- The share of non-collective tube-well ownership (Private, %) is treated as the dependent variable.
- Water-resource endowments are represented by two variables, average groundwater table in the last year (Wtable, meter) and the share of surface-water use in irrigation (Wsource, %).

Table 8. Relationship between tube-well ownership innovation and market development, water finance and credit policy.

Grouped in share of non-collective tube-well ownership (%)	Average share of non-collective tube-well ownership (%)	Share of villages that received water finance subsidy (%)	Share of villages that received water credit (%)	Share of villages with road (%)	Year	Average share of non-collective property right (%)	Share of villages that received water finance subsidy (%)	Share of villages that received water credit (%)	Share of villages with road (%)
0	0	23	62	51	1983	17	6	50	47
1-50	30	31	50	81	1990	44	23	53	73
51-99	77	48	56	88	1997	68	47	53	77
100	100	31	31	77	1998	69	47	53	77

Source: See table 1.

- Both per capita real net income of farmer (income, yuan/year, in 1990) and per capita real income of village collective (revenue, yuan/year, in 1990) represent the local economic power.

- Local human capital is represented by the share of agricultural laborers who received a middle-school or higher education (Edu, %).

- Per capita cultivated area (cultivated area/person, ha) indicates the state of the existing environment (Land).

- We select two policy dummy variables for water-finance policy (Finance) and water-credit policy (Credit), so as to represent the presence of water-policy influence. If there are water-finance subsidies available, then Finance = 1; otherwise, Finance =0; if there is water credit, Credit = 1, otherwise, Credit = 0.

- A road dummy variable (Road) is selected to represent the state of market development; if Road = 1, it means that there is a road in the village; otherwise, it means no road exists in the village.

- In addition, we also introduce regional dummy variables and time dummy variables. Regional dummy variables (Dv_{it}) indicate the impact of constant differences among regions on tube-well ownership innovation while time dummy variables (Dy_{it}) control for the impact of all factors that will change with time, on tube-well ownership innovation.

Selection of Estimation Methods

Four periods in 30 villages of cross-section and time series are used for estimating equation (1), making the total sample size 120. First, we used ordinary least squares (OLS) to estimate the equation which included all village and time dummy variables. Second, similarly, we estimated equation (1) by OLS while no village and time dummy variables were included. Finally, we adopted a random-effects model estimated by the maximum likelihood approach. The random-effects model assumed that the differences in e_{it} for various regions and periods are random. At the same time, we transformed some variables into a logarithmic form, such as groundwater table level in the last year, per capita cultivated area, per capita real net income of farmers and per capita real income of villages. As a result, 12 models have been estimated.

Estimation Results

The estimation results, for the various models, are satisfactory and the R^2 varies between 0.46 and 0.83, while the F and Chi^2 tests are also statistically significant (table 9). The fact that the estimation results from the various models are almost the same implies that the estimated coefficients are stable. Most variable coefficients are statistically significant and the signs of the coefficients conform to our expectations. Most village coefficients are statistically significant at the 5 percent or 10 percent level, which implies that other village factors, except for those explicitly considered in the models, will have impacts on tube-well ownership innovation. The estimation results also show that the time-dummy variables are not statistically significant, which implies that the variations seem correlated to the specific factors included

Table 9. Estimates for econometric model of tube-well ownership innovation determinants.[a]

Dependent variables	Private (%)		
	OLS		
	Case 1	Case 2	Random effect model
Constant	-132.022	-404.156	-111.367
	(-0.69)[b]	(-4.55)***	(-1.99)**
Water-resources endowments			
Ln (Wtable)	4.817	66.031	13.246
	(1.39)	(3.33)***	(2.64)***
Wsource (%)	0.430	0.435	0.455
	(2.72)***	(3.07)***	(3.21)***
Environment			
Ln (Land)	-3.262	-83.075	-31.740
	(-0.27)	(-2.54)**	(-1.90)**
Local economy			
Ln (Income)	-9.370	-11.570	-11.740
	(-1.11)	(-0.91)	(-1.23)
Ln (Revenue)	-4.074	1.340	0.250
	(-1.82)*	(0.72)	(-0.13)
Human capital			
Edu (%)	1.979	0.038	1.595
	(5.54)	(0.07)	(4.06)***
Policy dummy variables			
Finance	9.359	13.479	13.873
	(1.25)	(2.06)**	(2.12)**
Credit	-27.680	-62.107	-30.018
	(-4.14)***	(-2.10)**	(-2.90)***
Market development dummy variables			
Road	13.383	21.947	19.037
	(1.84)**	(2.24)**	(2.29)**
29 village dummy variables[c]	-[d]		-
R^2	0.458	0.833	0.619
Adjusted R^2	0.413	0.755	-
F	10.31	10.63	-
Chi^2	-	-	137.77
Degree of freedom	110	81	110

a = Sample size is 120.
b = Numbers in brackets represent t statistic test (case 1 and case 2) or Z statistic test (Random effects model); *, ** and *** represent statistic significance at 10%, 5% and 1% levels, respectively.
c: In order to save space, coefficients of village dummy variables have not been listed. Estimating results show that most coefficients of independent variables are statistically significant.
d: "-"indicates that the variable has not been included in the model or there is no estimating of them.

in the model and not just a correlation with general trends over time. In order to save space, we have not listed the estimation results of time dummies. In this paper we have reported only three estimation models.

Based on the estimation results of the econometric model, the following section will summarize major factors that induce tube-well ownership innovation.

Increasing water scarcity is one of the most important factors that induce non-collective tube-well ownership innovation. The estimation results of the econometric model show that the coefficient on the groundwater table level, in most models, is statistically significant at the 1 percent level and that the coefficient sign is positive (table 9). Therefore, ceteris paribus, the lower the level of the groundwater table, the higher the water-resources scarcity, and the greater the possibility of transformation towards non-collective tube-well ownership in GWIS from collective property rights. Table 9 shows that the coefficient of the groundwater table level variable is 4.8, which indicates that if the groundwater table level drops by 1 percent, then the share of non-collective tube-well ownership in GWIS will rise by almost 5 percent (4.8%).

Increasing groundwater exploitation will result in development of non-collective tube-well ownership. The coefficient on the share of surface water use is statistically significant at the 1 percent level and is of negative sign, in all the various models (table 9). The estimation results imply that, ceteris paribus, the greater the degree of groundwater exploitation, the greater the possibility of tube-well ownership innovation. Table 9 shows that if the share of surface-water use in irrigation declines by 1 percent, then the share of non-collective tube-well ownership of GWIS will increase by about 0.44 percent.

Both the groundwater table level and the share of surface-water use in irrigation are important indicators of water-resources scarcity. Our estimation results show that increasing water scarcity is an important factor in determining the degree of tube-well ownership innovation of GWIS, which supports the theoretical assumptions of institutional innovation induced by natural-resources scarcity.

Deterioration of the resource environment will induce non-collective tube-well ownership innovation of GWIS. The estimation results show that the coefficients for per capita cultivated area are all statistically significant at the 5 percent level and their signs are negative (table 9). That is, ceteris paribus, the smaller the per capita level of cultivated area, the greater the deterioration of the resource environment, and the greater the possibilities for tube-well ownership innovation of GWIS.

Weakening of village collective or community power will lead to non-collective tube-well ownership innovation of GWIS. The coefficients on the per capita real income of collectives are statistically significant at both the 5 percent and 1 percent levels, and the signs are negative. These results indicate that, ceteris paribus, the weakening of the economic power of the collectives will induce non-collective property innovation of GWIS. Table 9 indicates that the coefficient of per capita income of the collective is 11.44, which means that if the per capita income of the collective decreases by 1 percent, the share of non-collective tube-well ownership within the GWIS will increase by 11.44 percent.

However, tube-well ownership innovation of GWIS is not responsive to increases in the per capita real net income of farmers. Our estimation shows that the coefficient on the per capita real net income of farmers is not statistically significant and that, furthermore, if we drop the variable from the model, there is not much of an effect on the model estimation results. Due to limited space, we have not listed these model results. This result implies that an improvement in farmers' income has little effect on non-collective tube-well ownership innovation.

Therefore, as far as the effect of local-community economic strength goes, it is mainly collective economic power that has an important impact on tube-well ownership innovation of GWIS, while farmers' income has little effect on it. One possible explanation of this is that an individual farmer's income does not exert enough of an effect to influence tube-well ownership innovation. The above analysis also shows that the sharing of tube-well ownership is the predominant pattern within the GWIS. Sharing tube-well ownership within the GWIS not only allows farmers to share investment risk, but also serves to reduce the investment cost for every shareholder. Therefore, the sharing of tube-well ownership within the GWIS is a rational economic choice, given the farmers' current economic status.

Improvement of human capital within the local community can obviously induce non-collective tube-well ownership innovation of GWIS. Coinciding with our expectations, most of the coefficients on human capital are statistically significant at the 1 percent level and have a positive sign (table 9). It indicates that, all other variables remaining constant, the higher the educational level of agricultural laborers, the greater the possibility for the innovation of tube-well ownership. Table 9 shows that the coefficient of human capital is 1.979, and implies that if the share of agricultural labor receiving middle-school or higher education increases by 1 percent, then the share of non-collective tube-well ownership within the GWIS will increase by about 2 percent (1.979%).

Water-finance policy has promoted non-collective tube-well ownership innovation, but water-credit policy has hindered tube-well ownership innovation. In concordace with our expectations, the signs of the water-finance policy coefficients are all positive and statistically significant at the 5 percent level (table 9). The estimation results indicate that, ceteris paribus, the water-finance policy, with subsidies available to both villages and farmers, has had an important positive effect on tube-well ownership innovation.

Estimation results of the impacts of the water-credit policy also conform to our expectations. The coefficients on the water-credit policy are statistically significant, and their negative sign indicates that water credit, which is available to villages but not to farmers, has had a negative effect on tube-well ownership innovation.

Market development has an obvious positive correlation with non-collective tube-well ownership innovation. In agreement with our theoretical expectations, most of the coefficients on the road dummy variables are statistically significant at the 5 percent level and have a positive sign (table 9). Keeping other factors constant, the higher the development of the level of transportation, the greater the development of the markets, which implies even greater possibilities for non-collective tube-well ownership innovation.

Table 10. Relationship between tube-well ownership innovation and market development, water finance and credit policy.

By share of non-collective property right (%)	Sum	Wheat and maize	Others	Sum	Cotton	Others
0-0.99	90	74	16	10	7	3
1-89.9	89	79	11	11	6	5
90-100	88	80	8	12	7	5

Source: See table 1.

Table 11. Estimates for econometric model of cropping-pattern determinants.

Independent variables	$Area_G$		$Area_C$		$Area_o$	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
Constant	82.530	99.377	7.448	-10.100	10.022	10.723
	(25.19)***	(13.14)***	(2.39)**	(-1.41)	(5.69)***	(2.64)***
Private	-0.078	-0.082	0.033	0.039	0.045	0.043
	(-3.42)***	(-3.63)***	(1.54)	(1.83)*	(3.63)***	(3.54)***
Ln (Quota)	3.029	2.964	-0.730	-0.649	-2.299	-2.315
	(4.07)***	(3.99)***	(-1.03)	(-0.92)	(-5.75)***	(-5.82)***
Wsource	0.031	0.028	-0.023	-0.019	-0.008	-0.009
	(0.92)	(0.83)	(-0.72)	(-0.59)	(-0.44)	(-0.50)
$Price_G/Price_f$	—	2.604	—	-3.336	—	0.732
	—	(0.15)	—	(-0.20)	—	(0.08)
$Price_C/Price_f$	—	-5.430	—	5.713	—	-0.283
	—	(-2.90)***	—	(3.21)***	—	(-0.28)
Nincome	0.108	0.095	-0.054	-0.037	-0.054	-0.058
	(1.81)*	(1.65)*	(-0.96)	(-0.67)	(-1.69)	(-1.88)*
Adjusted R^2	0.43	0.43	0.40	0.40	0.29	0.23
F	10.86	12.26	9.66	10.83	5.41	6.06

Note: *, **, ***, represent statistical significance at 10 percent, 5 percent and 1 percent, respectively. Estimation results of county and year dummy are omitted.

Impact of Tube-Well Ownership on Cropping Patterns

Our sample data indicate that there is a positive relationship between non-collective tube-well ownership and the share of cash-crop areas. When the share of non-collective tube-well ownership increases from less than 1 percent to more than 90 percent, the share of grain-crop areas declines from 90 percent to 88 percent, while the share of cash-crop areas increases from 10 percent to 12 percent (table 10). Therefore, the greater the share of non-collective property rights within a GWIS, the greater the share of area under cash-crop cultivation and the lower the share under grain crops. However, cropping patterns are also correlated with other factors, such as grain-procurement policy, relative price of input and output, relative price of grain and cash crops, farmer income and labor-opportunity cost.

In order to control other factor influence, we specified the following model to explore the relationship between tube-well ownership innovation and cropping patterns:

(2) $Area_{ijt} = F\,(Private_{jt}, Wsource_{jt}, Quota_{jt}, (Price_g/Price_f)_{jt-1}, (Price_c/Price_i)_{jt-1}, Nincome_{jt}, Dc_j, Dy_t) + e_{it}$

- In the above equation, i represents each crop (including grain crops, cotton and other cash crops), j, the village and t, the time period.
- Areait represents the share of cultivated area of crop i of the total crop area in period t and village j, such that AreaGjt is for grain crops, AreaCjt is for cotton and Areaojt is for other cash crops.
- Private represents the share of non-collective property right of GWIS predicted from equation (1).
- The variable Quota represents the per capita grain procurement quota (kg/person), which will measure the effect of the government grain purchase policy on cropping patterns.
- $Price_G$, $Price_C$, and $Price_f$, represent the market price of grain crops, the purchase price of cotton and the price index of fertilizer input, respectively. Since cropping pattern is mainly influenced by the price expectation instead of the price of the current year, here we use last year's price to indicate the price expectation.
- The prices of natural resources and opportunity cost of agricultural labor are usually measured by shadow prices, so we select the share of surface-water use in irrigation to reflect water-resources scarcity (Wsource,%) and the share of nonagricultural income (Nincome,%) to capture the opportunity cost of agricultural labor.
- In order to explain the impact of differences between regions and years on the cropping pattern, we select county dummy variables Dc_j, and dummy variables for the year Dy_t.

The model performs well and the adjusted R^2 range of 0.23 to 0.43, is high enough for the estimation (table 11). Most variables in equation (2) are statistically significant and the signs are consistent with our expectations. For example, our results show that the per capita grain procurement quota has a positive relationship with grain-crop areas; the higher the price ratio between cotton and fertilizer, the larger the areas of cotton and the smaller the areas of grain crops.

More importantly, our results show the significant impacts of innovation of tube-well ownership on cropping patterns (table 11). The coefficient on the variable for the share of non-collective property rights within the GWIS is statistically significant at the 1 percent level, and has a positive correlation with the share of sown area of grain crops, while having a negative correlation with the share of sown area under cash crops. So, ceteris paribus, the innovation of non-collective property rights will have an influence on the cropping pattern changes of grain and cash crops.

In the grain-crops model, the coefficient of non-collective property rights is 0.082, which means that when the share of non-collective property rights within the GWIS increases by 10 percent (i.e., the average value increases from 42% to 52%), then the share of sown area of grain crops will be reduced by 0.82 percent (0.082×10=0.82) (table 11). Similarly, the share of sown area of cotton and other cash crops will increase by 0.39 and 0.43 percent, respectively.

Therefore, the development of non-collective property rights within a GWIS can be seen to play an important role in causing cropping pattern changes, especially that of increasing the cultivated area of high-valued crops. With tube-well ownership transferring from collective to non-collective, the reliability and timing of water supply have been enhanced inducing farmers to have more incentive to plant high-value crops. Due to the relatively higher marginal income from cash crops than from grain crops, farmers can earn more money with the adjustment of the cropping patterns.

Discussion and Recommendations

Based on a case study of groundwater irrigation systems, this paper analyzes the internal relationship between tube-well ownership innovation and its inducement factors, and the impacts of tube-well ownership innovation on cropping patterns. Research results show that tube-well ownership innovation within the groundwater irrigation system agrees with theoretical assumptions, and is induced by the following factors: increasing scarcity of water resources and groundwater exploitation, a declining resource environment, a weakening of local community economic strength (mainly that of the collective), improvements in human capital, water-finance policy, water-credit policy, and market development. Tube-well ownership will continue to change with changes in these factors.

Changes in these factors occur gradually and slowly, and different forms of property rights will result in different benefits for society and water-resources use. Transferring tube-well ownership from collective to non-collective can promote the cash-crop development. This implies that if policy can rationally induce tube-well ownership innovation, then tube-well ownership innovation will promote sustainable water-resources development and create greater welfare for society.

Based on the above discussion, several policy recommendations are put forward, as follows:

Actively induce tube-well ownership innovation. It is difficult to effect changes to the continuing trend of increasing scarcity of water resources and worsening environment; but if tube-well ownership innovation within a GWIS is to remain heavily dependent on a deteriorating resource and environmental base, then we cannot expect it to occur quickly. At the same time, we do not expect tube-well ownership innovation to occur at the expense of resource and environmental sustainability. Therefore, the government should implement effective policy measures in order to encourage and induce tube-well ownership innovation.

Adjust water-finance and water-credit policies. To make the policy direction clear, the government should apply effective and rational water-finance and water-credit policies to induce tube-well ownership innovation. On the one hand, the government should extend water-finance subsidies for the development of non-collective tube-well ownership within the GWIS and, on the other, it should put more emphasis on developing rural credit markets, and improving credit access to farmers so as to improve their investment ability.

Accelerate the development of human capital. The government should increase investment in farmers' education, improve their knowledge and management ability, develop their market awareness and strengthen human-capital development, in order to accelerate tube-well ownership innovation and improve water-use efficiency.

Promoting integrated river-basin management, especivially addressing groundwater issues. Within the administrative jurisdictions of the river basin, water supply and demand, too many authorities having different interests control and manage groundwater and surface water resulting in various conflicts in balancing water use in the region. Faced with increasing water shortage and groundwater depletion especially in North China, it is urgent to realize the integrated water management between water supply and water demand, and between groundwater and surface-water resources in the river basin.

With tube-well ownership being transferred from collective to non-collective, groundwater management is more distinct than before. If there is no rational and intergrated macro water policies to guide individual behaviors, it is possible that groundwater exploitation will be accelerated. Although farmers can get benefits from the ownership change in the short term, in the long term, with the further depletion of groundwater resources and if groundwater is not utilized and planned in a sustainable way, finally farmers will deplete all the available groundwater resources, and their production and environment will be greatly destroyed. Therefore, how to take rational and effective measures (such as groundwater resources fee, withdrawal permit system, etc.) to promote the sustainable water and socioeconomic development has to be emphasized by the policymakers and reseachers.

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Development of Water-Management Institutions in the Mae Klong River Basin, Thailand

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Introduction

The "Regional Study on Development of Effective Water Management Institutions" project was originally planned for five countries: China, Indonesia, Nepal, Philippines and Sri Lanka. In 2001, during a regional workshop held in Indonesia, Thailand expressed interest in participating in the project. A new work plan was created for Thailand and research was begun on the Bang Pakong and Mae Klong river basins in Thailand. This chapter presents the findings from the study of the Mae Klong river basin.

A goal of the project was to develop methods to link assessments of physical characteristics, water accounting, irrigation-performance assessment, and socioeconomic analysis in a manner that would improve the management of scarce water supplies within river basins. The overall purpose was to develop a framework for water management that would be comprehensive and integrated, participatory and responsive, and dynamic and strategic. Within this framework, policies and institutions could be improved and strengthened that would, in turn, improve the management of water resources. This chapter starts with an overview of the Mae Klong basin, and is then organized according to the three components of the study: water accounting, socioeconomic analysis and irrigation-performance assessment, and institutional analysis, followed by conclusions and recommendations.

Mae Klong River Basin

The Mae Klong basin drains approximately 30,800 square kilometers in the western part of Thailand. Thailand is subject to the southwest monsoon during the period from May to October and tropical cyclonic storms from the South China Sea during the end of the rainy season between September and October. Annual rainfall ranges between 900 and 1,500 mm per year, with an average annual rainfall of between about 1,000 to 1,300 mm per year. Due to Thailand's location in the tropical latitudes, temperature is uniform throughout the year with small seasonal variation around the mean of 28 °C. The average temperature in the hottest month (April) is 32 °C while the average temperature in the coldest month (December) is 25 °C.

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Among the twenty-five main river basins in Thailand, the Mae Klong river basin has some of the most abundant water resources. Forest covers more than 55 percent of the total basin area, compared to less than 25 percent for the country as a whole. The Mae Klong river is fed by two main tributaries: the Khwae Yai and the Khwae Noi, which are regulated by large multipurpose reservoirs, Srinagarin and Vajiralongkorn, respectively. Both supply water to the Mae Klong diversion dam in the downstream region of the Kanchanaburi City. The most intensive water-use zones are located in the lower part of the basin. It comprises a number of urbanized areas along the river and the Greater Mae Klong Irrigation Project (GMKIP), one of the largest irrigation-service areas in Thailand.

A large amount of water originates in the upstream drainage basin to feed the three million *rai* (480,000 hectares, 1 rai=0.16 ha) of the GMKIP. Yet, inadequate water supply for downstream irrigated paddy cultivation and domestic uses persists. Current plans call for water from the Mae Klong river to be diverted for the domestic water supply of the Bangkok area by the Bangkok Water Authority.

For this study, the basin was divided into seven areas: Khwae Noi upper basin, Khwae Noi lower basin, Khwae Yai upper basin, Lam Pachi, Lam Taphoen, Mae Klong Plain, and the GMKIP (see annex 1). These subdivisions are based on topography, land use, and the existing location of gauging stations for the convenience of water-accounting analyses. The seven areas were assigned abbreviated codes as shown in table 1. Khwae Noi and Khwae Yai are primarily forested areas with only a small portion of agricultural land. The Lam Taphoen is a tributary of Khwae Yai and most of the area is used for rain-fed agriculture. However, a medium-scale reservoir in the Lam Taphoen basin has almost been completed, with irrigation canals under construction and the project is expected to be operational within a few years. Lam Pachi is the only subbasin that has no medium or large-scale irrigation systems, and it has a serious problem with soil erosion. The plains area is divided into two: the upper plain area, which has no big irrigation systems and the GMKIP where most of the area is irrigated.

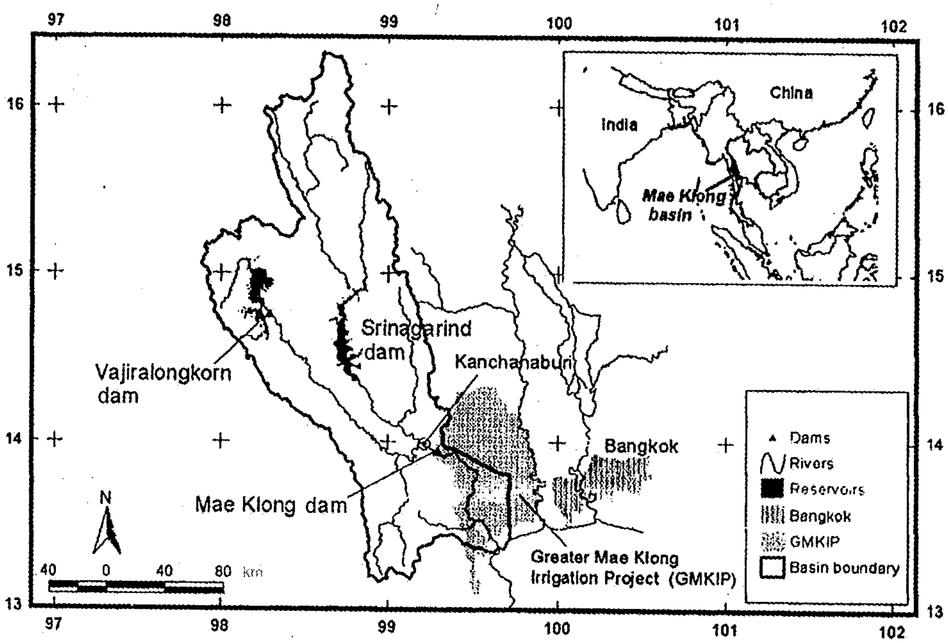
Table 1. Code abbreviations for study areas in the Mae Klong river basin.

Area Names	Code
Khwae Yai Upper	KHY
Lam Taphoen	LTP
Khwae Noi Upper	KHN-U
Khwae Noi Middle	KHN-M
Lam Pachi	LPC
Mae Klong Plain Upper	MK-PU
Greater Mae Klong Irrigation Project	GMKIP

The GMKIP consists of 10 irrigation projects: Phanomthuan, Songphinong, Banglen, Kamphaengsaen, Nakhonpathom, Nakhonchum, Thamaka, left bank Ratchaburi, right bank Ratchaburi, and Dumnernsaduak projects. The Dumnernsaduak project is a combined irrigation and flood-control project. As shown in figure 1, the official boundary of the Mae Klong river basin encompasses only 45 percent of the GMKIP, while more than half of the GMKIP's irrigated area is in the Thachin river basin. In order to consider the entire water uses in the basin, the GMKIP is totally included in the analysis.

In this report, data are usually presented from upstream to downstream. The map in figure 1 provides a more accurate illustration of the rivers. The upstream areas are generally more forested and less densely populated than downstream areas. Movement downstream corresponds to increased proximity to more densely populated urban centers, particularly Bangkok.

Figure 1. The Mae Klong river basin.



Water-Accounting Analysis

Water accounting was carried out to provide a basin-level summary of water availability and use across sectors. Water accounting for this study was done based on methods developed by IWMI researchers (Molden 1997; Molden and Sakthivadivel 1999).

Rainfall. Daily rainfall data from the Royal Irrigation Department (RID) were available for the study. More than 300 rain-gauge stations in 10 provinces that share the area with the Mae Klong river basin were investigated. However, only 58 stations were found to be within the boundary of the Mae Klong river basin. Among these, a limited number of stations provide usable information due to the intermittent recording and the regulated streamflow from the upstream dams. Two or three stations per subbasin, with a total of 20 stations, were selected on the basis of representative characteristics of the stations and data availability. Most of the stations have rainfall data in digital format beginning from 1952. The consistency of the rainfall records was carried out by the double-mass analysis technique, before the estimation of monthly and yearly mean annual rainfall using the Thiessen polygon method.

Inflow. The estimation of inflows in the main tributaries of Mae Klong river was based on the data from the gauge stations and water budget analyses at the storage dams. Some information from previous studies (AIT 1994; Kositsakulchai 1997, 2001; Rajasekaram 1997) was also taken into consideration in order to validate the data.

Storage change. The reservoirs of Srinagarind and Vajiralongkorn storage dams constitute the main surface storage in the basin. Information on reservoir operation, including the reservoir-storage variation, was provided by the Electricity Generation Authority of Thailand (EGAT). For the annual accounting, the changes in storage appear negligible. Conversely, they play an important role in the seasonal water-accounting analysis between dry and wet periods.

Trans-basin diversions. Water is now diverted to the Tha Chin river via two main drains of the GMKIP, Jarakae Sampham and Thasan-Bangpla canals. The maximum discharge of 80 m^3/s is anticipated from January to June during the dry-season cultivation in the Lower Chao Phraya West Bank area of the Central Plain.

The Metropolitan Waterworks Authority (MWA) initiated the Bangkok Metropolitan Water Supply Project in order to ensure potable water supply for a forecast population of 15 million in 2017. The MWA pumps water directly from the Tha Chin river. The diversion from the Mae Klong river at the design discharge of 45 m^3/s will begin within the next 15 years, when the construction of the new delivery canal is completed.

Crop consumption. The estimation of water volume depleted by crop evapotranspiration is based on water balance analyses. The potential evapotranspiration is derived from Class-A-pan-evaporation data. The adjustment factors for the derivation are those recommended by the FAO. The results of estimation by the main types of land use are summarized in table 2.

The depletive uses by crops can be divided into three groups. The beneficial process depletion is found in agricultural and irrigation-service areas. Evaporation from the forest area is also considered as beneficial, but non-process, depletion. Finally, water evaporated from other types of land cover, such as water bodies, is categorized as non-beneficial, non-process depletion.

Table 2. Area and estimated evapotranspiration (ETa) of the main crops in the Mae Klong basin.

Crop type	Area		ETa
	km^3	%	km^3
Paddy field	2,872.90	8.80	3.1
Sugarcane	4,370.30	13.40	4.5
Field crop/Vegetable	929.5	2.90	0.7
Orchard	969.8	3.00	1.4
Aquaculture	76.2	0.20	0.1
Forest	20,487.60	63.00	16.4
Water body	881.6	2.70	1.2
Others	1,943.70	6.00	1.8
Total	32,531.60	100.00	29.3

Domestic and industrial uses of water. Studies on domestic and industrial use of water in the Mae Klong river basin were conducted by AIT (1994) and the Mahidol University (1994). The AIT study estimated an annual volume of 17.6 million cubic meters ($m^{3)}$ for use in 1996 and 30.7 million m^3 in 2001. The Mahidol University reported the use of 27.7 million m^3 for five provinces situated in the lower part of the Mae Klong river basin. According to the previous studies, the volume of 30 million m^3 per year is estimated for the domestic and industrial uses of water in the Mae Klong basin.

Outflow. Outflows from the Mae Klong basin consist of two parts: surface outflows from the river and from drains. Records of stream flow of the Mae Klong river and its tributaries were used for estimating the outflow from the area of interest. A monthly water-balance model was applied in order to estimate the excess water drained from the irrigation-service area.

Commitments. A discharge of 40 m^3/s is recommended by AIT (1978) in order to control salinity intrusion at the mouth of the Mae Klong river. The minimum releases of 50 m^3/s from the Mae Klong dam are adopted for this purpose. This discharge, considered as committed flow, also incorporates the uses of water along the river.

Water accounting at the basin level. At the basin level, annual data were analyzed by using 10-year average data between 1989 and 1998. Rainfall represents the entire inflow of 39 km^3 into the basin (table 3). Constant storage is assumed for the annual analysis. Around 75 percent

Table 3. Mae Klong river-basin water accounting: Current condition, with planned trans-basin diversion in 2017 (km³).

	Current		Planned for 2017	
	Volume	Total	Volume	Total
Inflow				
Gross flow		39.151		39.15
Precipitations	39.15		39.15	
Surface inflow	0.00		0.00	
Storage change		0.00		0.00
Surface	0.00		0.00	
Net flow		39.15		39.15
Depletive use				
Process depletion		9.88		9.88
Evapotranspiration	9.85		9.85	
Municipal and industrial uses.	0.03		0.03	
Non-process depletion		19.43		19.43
Beneficial (forest evaporation)	16.42		16.42	
Non-beneficial (others evaporation)	3.01		3.01	
Total depletion		29.31		29.31
Outflow				
Total outflow		9.87		9.87
Surface outflow from river	6.31		3.92	
Surface outflow from drains	3.16		3.16	
Trans-basin diversions	0.40		2.79	
Committed water		1.98		4.37
Trans-basin diversions	0.40		2.79	
Saltwater intrusion	1.58		1.58	
Uncommitted outflow		7.90		5.50
Utilizable	7.66		5.26	
Non-utilizable	0.24		0.24	
Available water		36.93		34.54
Available for irrigation		36.90		34.51
Indicators				
Depleted fraction (gross)		0.75		0.75
Depleted fraction (net)		0.75		0.75
Depleted fraction (available)		0.79		0.85
Process fraction (depleted)		0.34		0.34
Process fraction (available)		0.27		0.29

of inflow is depleted by evaporation and transpiration from the basin. Since the forest covers more than 60 percent of the basin area, its evapotranspiration has a volume of 16.42 km^3 or half of the depleted water from the basin. From the environmental point of view, this evaporation is considered as beneficially depleted water.

The stream flow appears to be the highest outflow, of 6.3 km^3, from the basin; this includes the committed water of 1.58 km^3 (50 m^3/s) for protecting agricultural areas close to the coastal zone from saltwater intrusion. Another important outflow is due to the drainage water from the GMKIP irrigation system. The estimated volume of 3.16 km^3 calls for attention to the utilization of basin water. Available water could be increased by reducing the drainage outflow. Under the existing uses of water in the basin, almost 80 percent of available water has already been depleted.

Situation in the next 15 years. With the ongoing trans-basin projects, the diversions will attain a maximum volume in 2017, for the Bangkok Metropolitan water supply of 45 m^3/s and for contribution to the dry-season irrigation in the Lower Chao Phraya Left Bank. The committed water will increase from 1.98 km^3 to 4.37 km^3. Although the average data analyses permit these planned diversions, the more frequent droughts during the last 10 years signal caution for water management.

Seasonal water-accounting analysis. The first 6 months of the year, January to June, are analyzed as the dry period and the last 6 months as the wet period. In general, all components of water accounting during the wet period are greater than those during the dry period with the exception of the trans-basin diversions. Twice the gross inflow can be observed in the wet period, while the depletive uses vary less, especially in the irrigation-service area (beneficially depleted water). The higher inflow in the wet period also introduces more outflows from the basin, which can be observed in the uncommitted outflow component. The committed water practically aims to maintain minimum stream flow and to contribute to dry-season cultivation in the Central Plain. The surface storage in the basin allows the depleted water in the dry period to exceed the gross inflow into the basin as indicated by the indicator DF_{gross}. The storage plays a significant role in sustaining water availability over the deficit period.

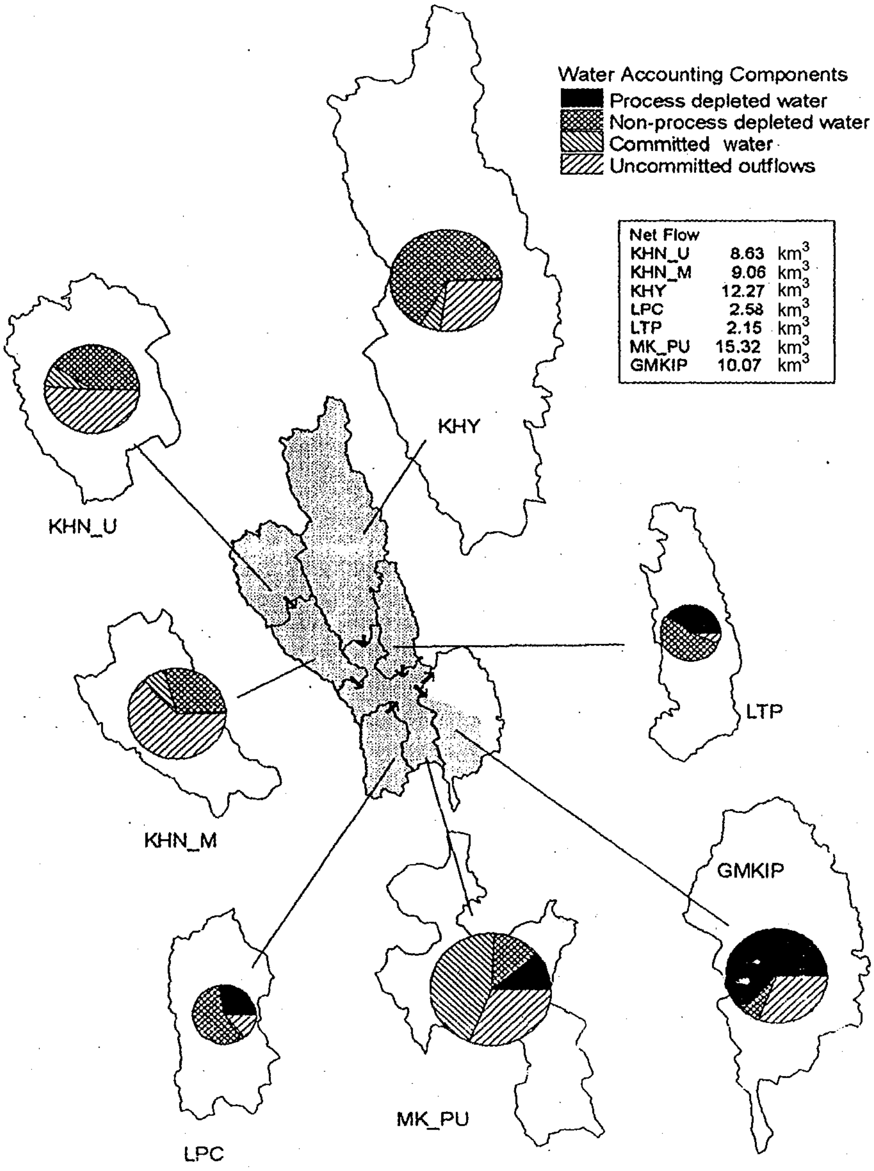
Water accounting in the Mae Klong subbasins. The second part of the water-accounting analysis considers the spatial variation of water use in different parts of the Mae Klong river basin. The basin was divided into seven parts according to hydrological characteristics and water-control facilities. The limits in the upper part of the basin can be defined by the drainage areas of the main tributaries: Khwae Yai (KHY), Khwae Noi (KHN), Lam Pachi (LPC) and Lam Tapheon (LTP). The Khwae Noi basin is divided into two subbasins at the location of the Vajiralongkorn storage dam (KHN-U and KHN-M). The Upper Mae Klong Plain (MK-PU) receives all flows from the upper part of the basin before diverting some water into the GMKIP.

The water-accounting components and indicators of each unit are presented in table 4 and figure 2. Three portions of the basin with different conditions of water uses can be noted according to the water-accounting indicators. In the upper part of the Mae Klong river basin (KHN-U, KHN-M and KHY), the moderated depletion fractions are mainly due to the evaporation from forest, while water uses by humans are very small as observed from the low process fractions. Two other tributaries of the Mae Klong river (LPC, LTP) produce a high depletion

Table 4. Water accounting in the Mae Klong subbasins.

	Subbasins						
Components (km^3)	KHY	LTP	KHN-U	KHN-M	LPC	MK-PU	GMKIP
Gross flow	12.27	2.15	8.63	9.06	2.58	15.32	10.07
Precipitations	12.27	2.15	8.63	4.02	2.58	4.32	5.18
Surface inflow	0.00	0.00	0.00	5.04	0.00	11.00	4.89
Storage change	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net flow	12.27	2.15	8.63	9.06	2.58	15.32	10.07
Depleted water	8.22	2.03	3.59	2.64	2.17	3.73	6.91
Process (irrigation evaporation)	0.17	0.86	0.03	0.10	0.72	1.68	6.30
Beneficial (forest evaporation)	7.48	1.06	2.90	2.10	1.33	1.51	0.04
Non-beneficial (other evaporation)	0.57	0.11	0.66	0.44	0.11	0.54	0.57
Outflow	4.05	0.11	5.04	6.42	0.41	11.60	3.17
Committed water	0.73	0.01	0.73	0.73	0.05	6.86	0.00
Uncommitted utilizable outflows	3.32	0.11	4.31	5.69	0.36	4.49	3.17
Uncommitted non-utilizable outflows	0.00	0.00	0.00	0.00	0.00	0.24	0.00
Available water	11.54	2.14	7.90	8.33	2.53	8.22	6.91
Indicators							
Depleted fraction (gross)	0.670	0.947	0.416	0.292	0.840	0.243	0.686
Depleted fraction (net)	0.670	0.947	0.416	0.292	0.840	0.243	0.686
Depleted fraction (available)	0.712	0.949	0.455	0.317	0.856	0.453	0.686
Process fraction (depleted)	0.020	0.425	0.007	0.036	0.333	0.450	0.911
Process fraction (available)	0.014	0.403	0.003	0.011	0.285	0.204	0.625

Figure 2. Main water-accounting components in the Mae Klong subbasins.



fraction and a moderate process fraction. These low-yield catchments encompass moderate agricultural activities outside of the irrigation-service zone. The concentrated zone of human activities downstream of the Mae Klong river is found in the irrigation-service unit (GMKIP); it has a relatively high depletion fraction and a high process fraction, which are due to intensive agriculture and urbanization.

Socioeconomic Analysis

This section profiles socioeconomic conditions in the river basin, analyzes performance indicators for irrigation, and draws lessons to link with the results from the institutional analysis and water accounting.

Macroeconomic Context

Thailand has been one of the more successful developing countries over the past few decades in terms of economic growth. Its GDP grew at an average annual rate of 7.6 percent during the 1980s. From 1980 to 2000, agriculture dropped from 23.2 percent to 10.5 percent as a component of GDP, while industry climbed from 28.7 percent to 40.1 percent. Approximately 40 percent of total labor is still employed in agricultural activities (Bank of Thailand 2002), but the greater part of the national income is now generated from the industrial sector. Thailand's GDP per capita for the year 2000 was reported as US$1,788 (Bank of Thailand 2002). According to World Bank statistics, the population of Thailand was 60.7 million in 2000 with an annual population growth rate of 0.8 percent. Using a poverty line of $1.50 per day, the poverty rate for all of Thailand in 1999 was 16 percent.

In 1997, Thailand was hit by the financial crisis that caused a dramatic increase in unemployment. While Thailand has undertaken several economic restructuring initiatives to address causes of the crisis, there remain several risks to the future of the Thai economy. Chief among these is the strong reliance of the Thai economy on exports. Even though the overall global slowdown appears to be abating, entry into the World Trade Organization by China will provide strong competition for Thai businesses (Maneerungsee 2002). While Thailand has taken great strides in strengthening its administrative structure and economic base, there are still great challenges ahead. It will become ever more critical for Thailand to maintain its advantages and resources.

Demographic Characteristics of the Mae Klong River Basin

The basin is characterized by high levels of employment in agriculture. Population and population density increase significantly in the downstream section of the Mae Klong and the GMKIP. The basin also experiences high rates of poverty according to Thailand's official poverty line (see table 5). The rates of poverty within the upstream portions of the basin are especially high when compared to the national poverty rate of 16 percent. However, the overall rural poverty rate for the basin is 11.5 percent. It can be seen in the table that the percentage of the poor who are employed in agriculture is very significant for those areas excluding the GMKIP. The percentage of poor females is roughly the same as poor males, averaging 49 percent for females (excluding the GMKIP study area).

Table 5. General socioeconomic indicators of the Mae Klong river basin.

Area name	Population	Rural population	Population density /km^2	Rural poverty rate	Female poor (%)	Poor in agriculture (%)
Khwae Yai Upper	78,919	72,359	14.1	79	51.4	83.0
Lam Taphoen	130,326	106,623	71.4	79	48.7	71.3
Khwae Noi Upper	39,039	35,634	10.2	46	46.0	81.9
Khwae Noi Middle	44,934	41,542	14.5	19	51.2	76.5
Lam Pachi	66,776	54,460	45.8	30	47.4	54.5
Mae Klong Plain Upper	395,085	278,337	144.6	2	51.3	76.5
GMKIP	1,446,490	1,046,652	342.0	0	0.0	0.0

Socioeconomic Stakeholder Analysis

An analysis of the various stakeholders in the Mae Klong river basin was conducted. The purpose of this exercise was to determine the relative wealth and influence of different groups as related to the role the stakeholder plays in water management. This information is summarized in table 6. A highly relevant aspect is that the irrigators are the least influential stakeholders in the decision-making process, despite the fact that irrigators are the largest users of water.

It can be further seen that the water user associations (WUAs) that have been formed in the basin raise the influence level of these stakeholders (although WUAs include all uses except hydropower). Given the relatively poorer status of irrigators this may indicate a need to extend and strengthen the capacity and role of the WUAs. The river-basin committee should include representatives from the WUAs in order to further strengthen the influence of this important user group. Irrigators and WUAs are the only stakeholders reported to suffer from seasonal water shortages. According to the constitution of WUAs, the management of irrigation is to be transferred to the local elected level (Tambon).

Another striking feature is the relatively influential position of the environment. One dam project, the Nam Chone Dam Project, has been rejected based on environmental concerns. This indicates the success that environmental groups are having in Thailand at raising awareness among, and influencing, key decision makers.

Poverty Situation in the Mae Klong River Basin

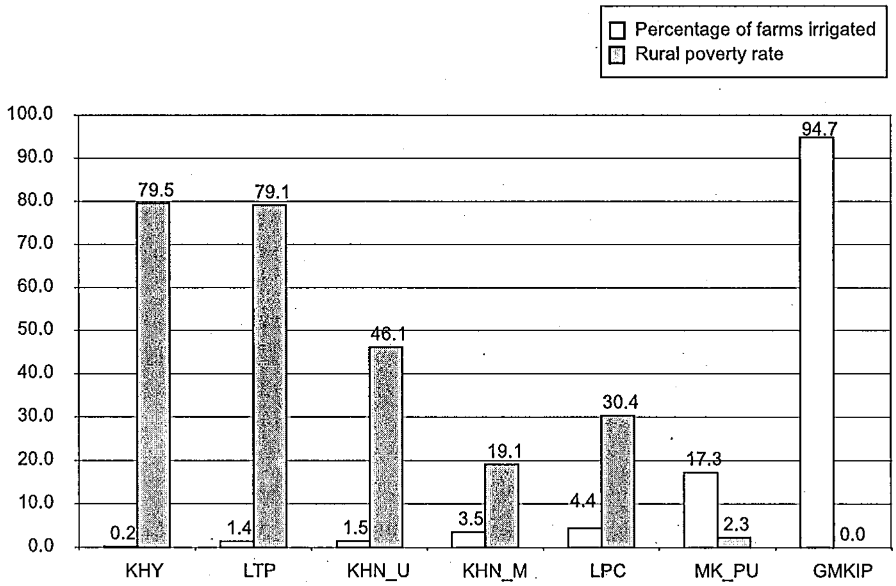
The rates of poverty within the upstream portions of the basin are especially high when compared to the national poverty rate of 16 percent. However, the overall rural poverty rate for the basin is 11.5 percent. As seen in table 6, most of the poor are engaged in agricultural activities. However, when comparing rural poverty rates with the percentage of farms irrigated, there appears to be an inverse correlation between poverty and irrigation (see figure 3). In the Lam Taphoen, it was reported that a new irrigation project is being constructed. However, the project is too new for any impacts on poverty to be realized. In the Khwae Noi study area, it was also reported that there are currently unofficial water withdrawals for irrigation that might

Table 6. Stakeholder analysis in the Mae Klong river basin.

Stakeholder	Source of water	Management level	Role in management	Relative wealth position	Relative influence position	Suffer from water scarcity
Irrigators	Field ditch/ gravity	On-farm	Plan with WUA and RID about amount and timing	Poor	Low	Seasonal
Domestic users	Pumping from surface water or groundwater	Project level at each water supply system	Provide source and deliver water to user	Non-poor	High	no
Industry	Pumping from surface water or groundwater	Project level for each factory	Extract the required amount from source	Non-poor	High	no
Environment	Reservoir/ Main river	Water quality at basin level	Control of water quality to meet the standard	—	High	no
WUA	Canal systems	From tributary to field ditch	Request in amount and timing	Non-poor	Moderate	Seasonal
RID	Basin	Irrigation system	Control and deliver water to tributary	—	High	no

explain the lower poverty rate. It must be remembered that the GMKIP and the Mae Klong Plain are the two areas most suitable for agriculture due to their flat landscape, while the upstream portions are mountainous and covered by forests. The use of irrigation as a potential instrument for poverty alleviation in the upstream portions would need to be carefully investigated. Additional factors that impact the poverty rates are access to significant markets and choice of crops.

Figure 3. Comparison of poverty rate versus percentage of farms irrigated, moving downstream on the Mae Klong.



Description of Agriculture in the Mae Klong River Basin

Agriculture claims larger portions of the total land area further downstream (table 7). This corresponds to the more favorable agricultural conditions in downstream areas. Agriculture accounts for about 85 percent of land use in the GMKIP. Moreover, this corresponds to an increase in the number of farms that are farmer-owned. However, in the downstream section there are over 90,000 landless farmers, which number is far greater than in any other section. Given the fact that there is no official poverty in the GMKIP, this gives another indication of the strength of irrigation's poverty-alleviation potential, especially beyond the owned farm unit.

The most significant crops in the basin are paddy and sugarcane, accounting for 27 percent and 34 percent, respectively, of total agricultural land in the basin (see table 8). Sugarcane is currently a largely under-irrigated crop. Areas where sugarcane is grown lack field ditches, have unsuitable terrain, or the farmers lack proper knowledge to irrigate sugarcane efficiently. Concerns were raised by some experts that potential changes in these patterns are not properly considered by current water-development plans, for example the interbasin transfer to send water to Bangkok. There has also been an increase in shrimp and prawn farming that makes unofficial use of the water in the GMKIP. These farms can have serious impacts on downstream water quality and adjacent land quality. However, effective arrangements do not exist for handling this conflict.

There are several trends that can be observed in paddy agriculture. There appears to be a declining trend in the income potential of paddy as measured as income (baht per rai). Within the basin, the two remote areas of the Khwae Noi Upper and Middle reaches experience lower income per rai than the other areas of the study. The Mae Klong Plain and the GMKIP have significantly higher incomes.

Another trend for major paddy is higher yields corresponding to locations further downstream. In all years reported, the GMKIP had the highest paddy yields of any area. The upstream areas experienced lower yields attributable to the less-favorable growing conditions, including a lack of irrigation. Khwae Noi Middle experienced the lowest yields, while having a relatively low poverty rate. This is explained by the relatively low area cropped with paddy. The Khwae Noi Middle area relied much more heavily on maize, cassava and sugarcane. Paddy prices were significantly lower upstream. Upstream farmers have fewer options in reaching potential markets and thus have less bargaining power when selling.

Table 7. Agricultural land use in the Mae Klong river basin, 1999.

Land use	KHY	LTP	KHN-U	KHN-M	LPC	MK-PU	GMKIP
Total (rai)	6,215,479	1,366,188	2,533,328	1,793,035	966,261	2,390,169	2,600,208
Agriculture (rai)	465,242	677,097	86,838	256,687	418,676	1,004,757	2,225,723
Forested (rai)	5,359,701	669,701	2,049,275	1,531,297	531,444	1,324,216	115,716
Reservoirs (rai)	378,571		391,245				
Urban (rai)	11,964	19,390	5,971	5,051	16,141	61,196	258,769
Irrigated farms (%)	0.22	1.38	1.52	3.55	4.4	17.32	94.75
Farmer land tenure situation							
Own number	10,431	12,542	2,672	5,233	6,417	30,530	90,300
Rent number	2,376	3,390	382	838	1,574	6,778	29,805
Landless number	8,102	11,072	1,612	2,716	3,433	24,304	115,900
Farm income (baht/year)	32,055	44,097	37,694	40,058	34,560	44,190	80,020

Note: 1 rai = 0.16 ha.

Table 8. Land area for each crop in the Mae Klong river basin (rai).

	KHY	LTP	KHN-U	KHN-M	LPC	MK-PU	GMKIP
Major rice	31,746	30,060	3,321	805	24,880	183,429	630,346
Second rice	0	6,408	88	578	6,050	91,211	497,057
Maize	33,751	36,108	27,393	51,987	509	23,659	7,443
Cassava	12,920	52,760	18,399	30,467	73,027	123,113	14,187
Sugarcane	238	294,335	308	40,806	87,028	293,238	415,727
Orchard	0	9,078	0	0	16959	18,821	85,643
Prawns	0	0	0	0	0	0	27,644
Fish	30	551	555	123	640	2,300	56,574

Irrigation-Performance Assessment in the Mae Klong River Basin

Indicators of irrigation performance were calculated based on methodology developed by IWMI. The data and calculated irrigation performance indicators of the major irrigation projects are given in table 9. All reported irrigation systems are located within the GMKIP. The most striking feature is that no irrigation revenues are reported. Irrigation management in Thailand does not include the collection of irrigation fees from farmers. This situation can create several problems for the irrigators and irrigation management. First, financial sustainability is not possible under the current conditions. The irrigation system will be completely dependent on government financing to remain operational. Second, dependence upon the government for operation financing weakens farmers' bargaining position within the water-management process. Dialogue with various experts indicated that a reversal of this practice is highly unlikely in the near future. A reluctance to charge and collect water fees removes a potential instrument to help regulate the use of water.

The performance indicators indicate a significant variation in performance across the different systems, especially in output per unit of land area. Given the relative proximity of these systems the variation would be an interesting point of investigation. The output per unit of irrigation water and output per unit of water supply are roughly equal for each system, but vary in accordance with variations in output values. Finally, the relative water supply and relative irrigation supply are roughly equal within and across systems.

Table 9. Irrigation-performance indicators.

	Irrigation system				
	Phanom thuan	Song phinong	Right Bank Ratchaburi	Nakhon pathom	Nakhon chum
Gross value of output (million baht)	2,335	2,682	5,607	8,474	7,631
Irrigated area (rai)	289,300	307,000	234,111	291,040	191,945
Command area (rai)	330,400	313,600	304,000	337,900	259,000
Water diverted to irrigation systems (mcm)	515	597	711	502	488
Total annual rainfall (mcm)	51	54	42	53	35
Rainfall (mm)	1,100	1,100	1,120	1,130	1,140
Crop water demand (mcm/year)	468	542	647	456	444
Total water supply (mcm/year)	566	651	-	-	-
Total irrigation supply (mcm/year)	515	597	711.00	502.00	488.00
Total O&M expenditure (baht/rai/year)	98	101	153	112	149
Government revenue from irrigation (baht/rai/year)	0	0	0	0	0
Output per unit of cultivated area (baht/rai/year)	8,071	8,736	23,950	29,116	39,756
Output per unit of command area (baht/rai/year)	7,067	8,552	18,444	25,078	29,463
Output per unit of irrigation water (baht/m^3)	4.5	4.5	7.9	16.9	15.6
Output per unit of available water (baht/m^3)	4.1	4.1	7.4	15.3	14.6
Relative water supply	1.21	1.20	1.16	1.22	1.18
Relative irrigation supply	1.23	1.22	1.18	1.24	1.19
Financial self-sufficiency	0	0	0	0	0

Competition and Conflicts for Water in the Mae Klong River Basin

There are a number of conflicts in the Mae Klong river basin. Many problems revolve around the issue of water quality. In a field visit to Damnernsaduak (along the coast), it was reported that upstream waste from pig farms and irrigation was negatively affecting water quality. Currently, the problem can be mitigated through dilution. However, if water scarcity continues to grow, this method of addressing the problem may no longer be feasible. Water-quality issues were also observed upstream where prawn farming is beginning to grow in scale. Currently, both the development of prawn farms and their use of water go largely unregulated. This conflict will be difficult to resolve as prawn farming yields much higher income per unit of land area than crops. As influence tends to be positively correlated with wealth, this could prove particularly troublesome to crop farmers. One possible approach to resolving this issue is the zoning of land, based on use, although enforcement would be a major hurdle.

Another major conflict in water use involves the irrigators and hydropower producers. Reservoir releases are controlled by EGAT whose objective is to produce electricity. While releases are planned in cooperation with the demands of irrigation, it is done only on a weekly basis. Daily releases are based on hydropower demands, which may conflict with the needs of downstream farmers. Greater cooperation would be needed between RID and EGAT to resolve this issue. A possible realignment of responsibilities and authority would be another avenue to explore.

Annex 3 lists other conflicts. In general, the conflicts persist due to a lack of proper enforcement of existing laws. Additionally, a lack of effective cooperation and the exclusion of relevant stakeholders are other major causes of persistent conflicts. While the Government of Thailand seems to have recognized these problems to the extent that they have formed an apex coordinating body that had established river-basin committees, there are still significant lapses in realizing the full potential of what has been established. Additionally, gaps in the current system (e.g., lack of a national water law) will continue to hinder the management of water resources within the basin.

Discussion of Socioeconomic Analysis

The analysis has offered a general profile of the socioeconomic situation in the Mae Klong river basin. Additionally, the report offers an analysis of the performance of irrigation within the basin. The results of the analysis show that, in general, an improvement in the management of water resources can have significant benefits to society. For example, the GMKIP appears to have a significant impact on poverty alleviation. However, localized improvements may create greater polarization of incomes within the basin. As incomes and influence on water-resources management seem to be correlated, this could create new problems unless deficient areas are made the target of development programs.

This is especially important in the still largely forested upstream portions of the Mae Klong river basin. These areas will need to be preserved in order to protect the quality of the water resources of the basin. However, increasing poverty can lead to detrimental effects on the health of the environment. Therefore, the improved management of water resources within the basin will also need to address poverty issues and the welfare of its inhabitants.

The results of the socioeconomic study strengthen the call for an improved water-management framework and institutions. While less than optimal water-resources management may result from a weak institutional structure, poor water-resources management may also have negative impacts on the socioeconomic aspects of the basin. These negative impacts may amplify and feedback on existing problems and conflicts in water management.

Institutional Analysis

National Institutions

There are more than thirty national agencies with various roles in water-resources management and delivery of services to water users. The three most dominant ministries in terms of water management have been the Ministry of Agriculture and Cooperatives (MOAC), the Ministry of Science Technology and Environment (MOSTE) and the Ministry of Industry (MOI).

At the policy development and coordinating level, several national committees play an important role regarding water-resources management. These include the National Economic and Social Development Board (NESDB), National Environment Board, Thai National Mekong Committee and the Chao Phraya River Basin Committee. These committees have carried out several aspects of coordination and regulation of water-resources management; however, none of these agencies have been responsible for the full range of required activities.

There are at least 28 water-related laws administered by over 30 departments overseeing water issues in eight ministries. Table 10 presents the titles of these laws classified as they pertain to quality or quantity issues.

Water-resources management has been complicated by gaps and overlaps in management responsibilities. The problems related to water-resources management in Thailand include:

- Policy and planning—there is no coordinated policymaking by the agencies concerned.
- Budgeting—at present, the budget is allocated to each agency upon request.
- Legal framework—there are several acts concerning water resources but no single act directly relates to water-resources management.
- Availability of information—because there are too many implementing agencies, information on water-resources development is not organized in a centralized manner.

There are many government agencies and private parties involved in the development and exploitation of surface-water and groundwater resources; however, cooperation and coordination between the different parties have been weak. Even when cooperation between operating agencies led to plans for equitable allocations of water, the plans were often challenged by affected parties. The result was often a compromise that simply postponed the problem to a later date. Recognizing the lack of coordination, the government decided to establish a central agency in water-resources management in order to formulate plans, coordinate plan implementation, and carry out other work concerning the management of water resources.

Table 10. Legislative enactments relating to water quantity and quality in Thailand.

Water quantity	Water quality
Canal Maintenance Act, 1903	Canal Maintenance Act, 1903
Water Hyacinth Elimination Act, 1913	Water Hyacinth Elimination Act, 1913
Private Irrigation Act, 1939	Navigation in Thai Waters Act, 1913
Royal Irrigation Act, 1942	Royal Irrigation Act, 1942
Dike and Ditches Act, 1962	Fishery Act, 1947
Minerals Act, 1967	Minerals Act, 1967
Metropolitan Waterworks Authority Act, 1967	Revolutionary Council Announcement No. 286, 1972
Electricity Generating Authority of Thailand Act, 1968	Groundwater Act, 1977
Groundwater Act, 1977	Provincial Waterworks Authority Act, 1979
Provincial Waterworks Authority Act, Act 1979	Building Control Act, 1979
Waterworks Canal Maintenance Act, 1983	Factory Act, 1992
Civil and Commercial Code	Public Health Act, 1922
	City Cleanliness and Tidiness Act, 1992
	The Enhancement and Conservation of National Environmental Quality Act, 1992
	Penal Code

In 1989, the Prime Minister's Regulation on National Water Resources Management created the National Water Resources Committee (NWRC) intended to be an apex body for water-resources management in Thailand. The NWRC was given the leading role in coordinating concerned agencies in planning and systematizing an information system in order to facilitate effective water-resources management. However, this goal has not been achieved because the NWRC lacked any permanent organization and recognition. Therefore, the Office of the National Water Resources Committee (ONWRC) was legally established late in 1996, which has carried out various activities to support improved information, policy and planning for water management.

The enactment of Thailand's new Constitution in 1997 has had significant influence on the government's natural resources and environmental policies, the implementation and operation of government projects, and the interpretation of relevant laws and regulations. The new Constitution not only provided for participatory management of natural resources, including water, but also established an obligation on the government administrations to implement this approach.

In a collaborative manner, the ONWRC and other relevant agencies formulated the National Water Vision in 1999. "By the year 2025, Thailand will have sufficient water of good quality for all users through an efficient management, organization, and legal system that will ensure equitable and sustainable utilization of water resources with due consideration to the quality of life and the participation of all stakeholders." Shortly thereafter, the national water policy was further developed in consultation with other stakeholders and was approved by the Cabinet in 2000.

Since its establishment, the NWRC has worked to strengthen the mechanism of integrated water-resources management in Thailand. A notable step forward was the drafting of a water-resources law. In order to implement the law, river-basin organizations or commissions would be established in each of Thailand's river basins. This recognized the need for decentralized management of water resources. According to the draft law, each river-basin committee would consist of qualified persons drawn from public and private sectors. A committee would develop policies on water-resources planning, development, operation of facilities, and water allocation. The river-basin committee would oversee all related activities in the river basin including the resolution of water-related conflicts between various water users.

Basin-Water Management

In the Mae Klong river basin, RID and EGAT are responsible for deciding how much water will be required by each sector, which is summed into the aggregate amount of water required to be distributed from reservoirs. Large-scale allocations refer to the distribution of water to the different sectors, such as domestic, industry, control of seawater intrusion and agriculture. Bulk allocation is made to resources managers and users, e.g., Provincial Waterworks Authority and WUAs. However, monitoring of the volume of water withdrawn by each customer is rarely done.

Small allocations for each sector are defined as follows:

- Household and industry—water fee is paid to service providers as the amount varies with the volume used.
- Control of seawater intrusion—oversight by RID.
- Agriculture—main canal overseen by RID and secondary and tertiary canals and on-farm level managed by WUAs. There is no water charge but farmers may pay the WUA for system maintenance.
- Allocation of groundwater—groundwater in the basin is free for use in terms of both price and control by law or regulation.

Reservoir Management

Coordination between RID and EGAT is made at the departmental level in order to make decisions on weekly reservoir releases and at the basin level for daily regulation of control structures. The operation of the Khao Laem and Srinagarind reservoirs is presently carried out responding to water demands of GMKIP, Mae Klong salinity control, and the Tha Chin river diversion. Lower and upper rule curves are established for the two reservoirs. At the departmental level, EGAT and RID cooperate in making decisions on weekly water releases for GMKIP, based on weekly RID requests for irrigation water use and other requirements.

Large-scale water-resources infrastructure, such as Khao Laem, Srinagarid and Tha Tung Na reservoirs, is operated by EGAT through its dam-site offices. As discussed above, the major water user for these reservoirs is the GMKIP, which is administered by RID through the Region Ten Office. At the basin level, there exists coordination between the EGAT dam-site offices and the RID Region Ten Office in the daily operation of regulating structures. However, the final decision is up to EGAT due to hydropower generation that has to be satisfied.

Past performance records show no shortage occurrences in either reservoir. In other words, all water requirements relying on the reservoirs were met. So far, there have not been any disputes concerning the amount of water release between RID and EGAT. However, it was reported during field visits that water releases do not conform to optimal timing for use by the irrigators; rather the weekly quantity requested is released in a manner most beneficial for the production of hydropower.

Water Management in the GMKIP

For many years, a computer model has been used to forecast weekly water demand at head regulators of the irrigation canals. Wetness conditions of paddy fields are observed and used as real-time input data for the model. The higher the field wetness, the lower the expected water demand for the next 7-day period. The model is installed at the computer center of the GMKIP office (in the RID Region Ten Office) and run by RID officers. To date, there have been no reported water-shortage problems in the GMKIP areas. Field interviews confirmed that water management within the GMKIP is able to satisfy the farmer demands. In other words, the timing and adequacy of irrigation water controlled by the GMKIP office are generally acceptable.

Small-Scale Irrigation

For small-scale irrigation systems, there are no RID workers stationed at the site. After construction is completed, the project is entrusted to the local Tambon Administrative Organization (TAO), which makes decisions on operations and maintenance. Occasionally, the Provincial Irrigation Office (PIO) will inspect the project for structural and hydraulic failures. The PIO will give technical advice to the TAO. Any repair budget is the responsibility of the TAO.

Pump Irrigation

Pump-irrigation projects are planned and developed by the Department of Energy Development and Promotion (DEDP), based on requests. Water is usually pumped directly from rivers. The energy cost for pumping water is charged to beneficiary farmers who form a water user group.

Waterworks

Waterworks for large cities are generally administered by the Provincial Waterworks Authority (PWA). The PWA scheme office will report to the PWA in Bangkok. The revenue derived from the particular scheme is sent directly to the PWA. A few waterworks schemes are administered by private concessionaires. Schemes in smaller cities are usually administered by the municipality, which reports to the Provincial Governor. The budget and personnel are handled by the municipality with consent from the Governor. Village waterworks are managed by the TAO. Their budget derives from local taxes and budget support from the central government. By 2006, all small water-resources projects will be transferred to TAOs.

Groundwater

The groundwater resources in the Mae Klong river basin are primarily obtained from the unconsolidated deposits of floodplains, deltas and terraces. In Tha Muang, Tha Maka, and

Ban Pong districts, at least three aquifers have been recognized at depths of up to 200 meters. The aquifers are very productive and yields from a well may range from 20 to 100 m^3/hr. Higher yields of around 150 m^3/hr can be obtained from a well with screening to allow water in from more than one aquifer. The groundwater quality of the three aquifers is generally good except in the areas south of Ban Pong to the Gulf of Thailand where shallow aquifers produce brackish to salty groundwater. Wells penetrating cavities of limestone in highland areas give high yields, but high hardness of water quality is normal. Yields of a well can be up to 50 m^3/hr or more and the water must be treated before use.

Mae Klong River-Basin Committee

For water resources of the Mae Klong river basin, the development and management activities are undertaken by a combination of the EGAT for large-scale reservoirs, RID for medium and small-scale reservoirs and irrigation areas, DEDP for small pump-irrigation projects, PWA for large domestic water-supply projects, and individual municipalities for municipal water-supply projects.

The Mae Klong riverbasin area consists of three provinces: Khanchanaburi, Ratchaburi and Samutsongkam. A letter from the Samutsongkam Province submitted on February 22, 2000 requested the ONWRC to establish the Mae Klong River Basin Committee (MKRBC) in order to more effectively manage floods, regulate saltwater intrusion, and address problems of freshwater scarcity and water pollution.

The ONWRC and Samutsongkam Province held a stakeholders' meeting on May 3, 2000, which involved participants from concerned government agencies, local administrators, representatives from water users from the agriculture and industrial sectors, and other relevant stakeholders. The purpose of the stakeholder meeting was to determine the composition, responsibilities, process and the selection of representatives that would make up the committee. The result of the meeting called for the establishment of an MKRBC as soon as possible.

In 2001, the MKRBC was established by the ONWRC with the cooperation of the governors of four provinces located within the river-basin area and other concerned government agencies. The objective of establishing the committee was to form an institution that would be responsible for water-resources management coordination and regulation of the river basin.

While its ultimate level of operations encompasses many perspectives and includes the bulk allocation of water as one of its functions, because of its recent establishment, the committee does not currently possess adequate capacity to perform the required work. Therefore, an implementing agency like the RID will need to be a key actor in allocating water both for large and small groups of users until the proper level of capacity is built.

Conclusions and Recommendations

The water-accounting component indicated the current situation of the basin. Currently, water is still adequate on an annual basis, but this situation may reverse under a number of scenarios that could come into being in the future. Among these scenarios is increased irrigation by sugarcane growers and increased diversions to Bangkok. Either of these scenarios could create a situation where water quantities are insufficient to meet demand.

The socioeconomic analysis and irrigation performance analysis highlighted the important role that irrigators play in water management of the basin. In particular, agriculture plays a significant role in the basin, both in terms of livelihoods and as a factor in poverty alleviation. However, it is also the sector with a significant portion of poverty. In general, farmers are not very influential in policymaking and decision making. They are, however, among the most vulnerable. If, as the water-accounting section seemed to indicate, the upstream portions become the targets of conservation programs, then careful planning will be needed to avoid environmental damage from an increasingly desperate population. It is a common occurrence in the region that when yields decrease and poverty increases in upland regions, then environmental degradation is accelerated.

Prawn farming is becoming an increasingly popular agricultural activity. The returns per rai are far higher than for any crops. However, prawn-raising activities can have many serious negative impacts, such as reduced yields in surrounding fields, polluted water released downstream, higher quantities of water used, and illegal abstraction of water to fill the ponds. An effective method needs to be implemented to balance the needs of all the various stakeholders. These methods can involve stricter enforcement of policies, incentives to discourage creation of externalities by prawn farmers, and compensation for injured parties.

In general, the position of farmers within the decision-making process needs to be strengthened. Farmers must have a stronger ability to influence policy. This can involve larger groups of farmers such as federations of water user groups. It can also involve high-level representation or membership in a high-level decision-making body.

Another significant conflict is between hydropower production (EGAT) and irrigators. Daily release schedules are determined, based on hydropower production needs, while weekly demand requests are made by the irrigators to EGAT. Since daily releases are made to suit hydropower-production needs, water is not delivered in a manner that is optimal for farmers. An examination of this conflict should be conducted to determine a more optimal operating schedule.

The institutional-analysis section indicated that many positive steps have been taken toward more effective management of river basins. These are, in particular, the recognition of the need for river-basin organizations to manage water from the basin perspective, the need to establish farmer organizations to represent farmers, and the need to better coordinate water-resources management among the many diverse agencies. However, more progress needs to be made to realize the ultimate goals of these changes. Foremost is the need to enact an effective and comprehensive national water law. The law should not only clearly spell out the duties and responsibilities of the different agencies but also clearly specify the authority each agency will have in enforcing its duties and regulations.

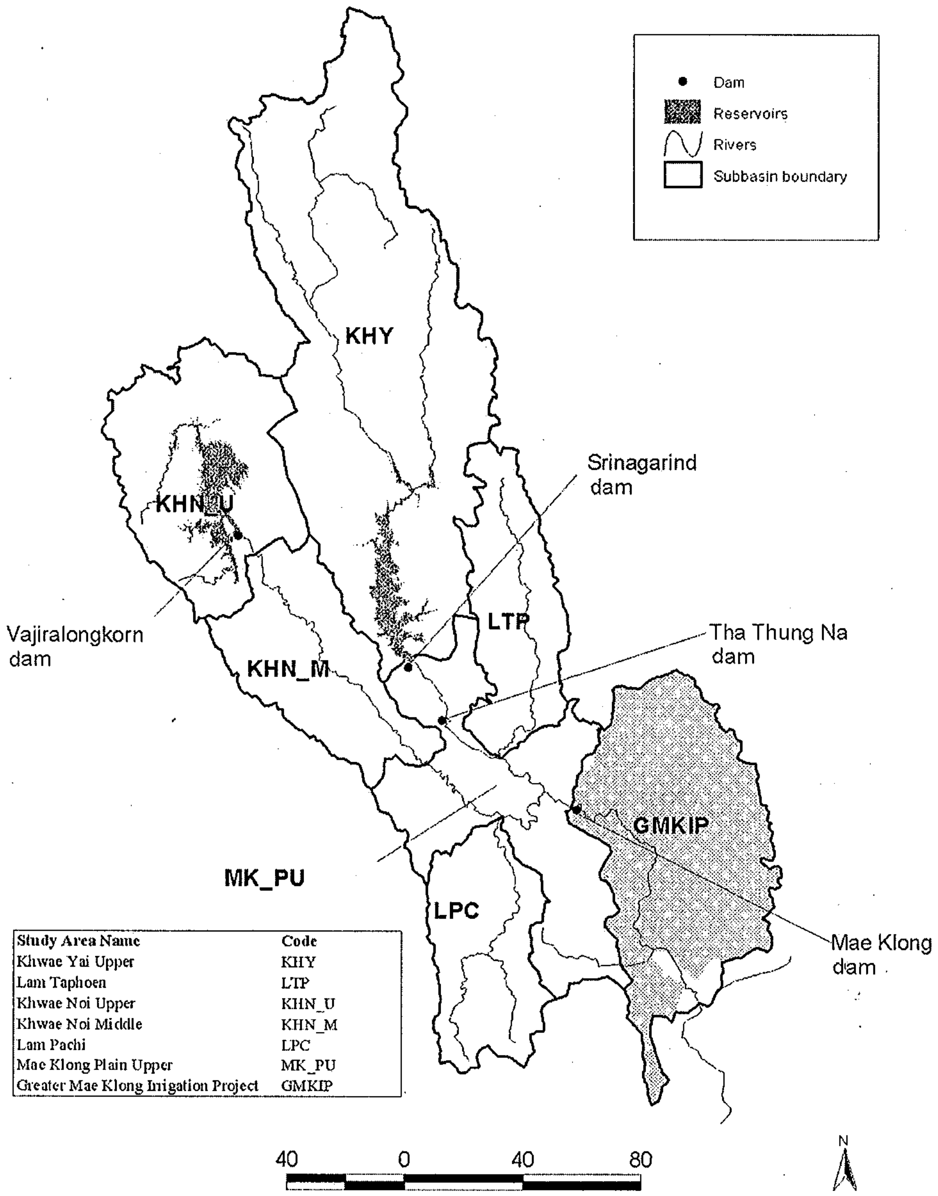
Recognition of the need for stronger local management has led to the formation of river-basin committees. This is a good fundamental move for better coordination of different agencies and representation of stakeholders at a more decentralized level. However, the current membership structure omits two important stakeholders; these are the Bangkok Metropolitan Water Authority and EGAT. As these are two of the most influential water users, their ability to manage water outside of consultations with the proposed river-basin committee's members could seriously undermine the effective management of the Mae Klong river basin.

There are many important water-management issues and problems in Thailand. In particular, the issues of water scarcity, poor water allocation, and a lack of a formal system of water rights create negative impacts for many water users, particularly those in downstream locations. Many agencies are involved in water-resources development and the provision of water services, but their activities are uncoordinated and often conflicting, resulting in poor efficiency in use and significant cumulative impacts on the resource. Additionally, there are concerns regarding watershed management; flood and drought problems; overuse of groundwater (particularly in the Bangkok area); water-quality concerns relating primarily to industry, municipal, and non-point source pollution; high cost of public water services; and inadequate sharing of costs with the beneficiaries. Information on water resources is not adequately shared between agencies or with water users. There is little involvement of water-resources stakeholders in the management decision process. Transparency and accountability need to be improved while the degree of polarization in the water sector needs to be decreased.

The biggest challenges facing the effective management of water resources in the Mae Klong river basin are:

- The improvement of interagency and stakeholder communication and cooperation.
- The effective enforcement of policies and regulations.
- The creation of effective institutions that are responsive to farmer needs and can influence the decision-making process.
- The creation of an incentive system to regulate/control/compensate for water-use patterns.
- The recognition of, and response to, increasing water scarcity.

Annex 1. Map of the Mae Klong river basin and seven study areas.



Annex 2. Legal setting of water-resources management in Thailand.

Title of lLaw and classification number:	Draft Water Resources Act	Groundwater Act 1977	Land Consolidation Act 1975	Classification of River Basin Act *	Ditch and Dike Act 1962	Irrigation Act 1942
Issuing authority: Department	ONWRC	Department of Mineral Resources	Office of Land Consolidation for Agriculture	Royal Forest Department	Royal Irrigation Department	Royal Irrigation Department
Scope	National	National	National Land	National	National	National
Aspect addressed:	All aspects of water resources management and utilization.	Registration of tube well.	Land consolidation program	Allowable land use for each basin classification.	Existence and maintenance of ditch.	Issued to support irrigation development.
Description of implementation procedures:	River Basin Committee is established by NWRC to perform function as assigned. In cases of dispute, RBC suggests resolution, can refer to NWRC for higher resolution procedures	All private boreholes must be registered, new boreholes must obtain a permit and annual fee should be paid. No permit is needed for government agency.	If the majority of farmers in the area agree with land-consolidation program. The OLCA will announce the land consolidation area and partially pay for the cost.	It prohibits all development including dam construction at the river basin class 1 (sloping area with good forest condition).	Farmers cannot invade the ditch and must do some maintenance at appropriate time.	Giving RID and its officers the authority in construction, operation, and maintenance of irrigation projects and systems.
Responsible parties:	NWRC, RBC	DER	OLCA	RFD	RID	RID
Enforcement mechanisms:	NWRC issues national policy and RBC issues basin strategy and management.	DER should monitor and check number of well and amount of pumping.	The target area is irrigation area and should be initiated by farmers.	RFD controls land use according to the classification of basin.	RID should inform farmers to do some maintenance of field ditch.	RID is recognized and authority was granted for its duty.

Annex 3. Trade-off analysis for the Mae Klong river basin.

Competing groups	Level of parties (macro, meso, micro)	Description of conflict	Trade-offs	Possible resolution and source
Hydropower/ Irrigators	Macro/Micro	Quantity of water released is enough for both purposes, but timing is determined solely by hydropower needs on a weekly basis.	Nonoptimal irrigation timing (indirectly reduces crop production) or loss of hydropower production.	Adjust the release policy for hydropower or construction of regulating dam (by RID) downstream of storage dam.
Rice/Freshwater shrimp farm	Meso	Shrimp farms use too much water (about 8 times as much as rice) so that there are water shortages at the tail end of the canal.	Rice and shrimp farms are in the same area. The shrimp farm is normally located at the head of canal.	Implement zoning for rice and shrimp farms; shrimp farms may treat and reuse the water to reduce the amount of water use.
Rice/Black tiger shrimp farm	Meso	Drainage water from shrimp farms reduces quantity of rice production and deteriorates soil condition.	Rice and shrimp farms are in the same area.	Implement zoning for rice and shrimp farms; the latter may be prohibited in the freshwater areas.
Fisherman/Pig farm and sugar mill	Meso	Wastewater from pig farms and sugar mills destroys the fish industry.	Pig farms and sugar mill factories are in the upstream area.	Wastewater should be properly treated before release to the watercourses.
Irrigators/Trans-basin diversion of water by BWA	Macro/Micro	Water diverted for Bangkok water supply.	Less water available in the basin. Irrigators may experience water shortages in the future.	BWA may pay water rights fee or compensation for the basin. The government must make a decision on this issue.
Irrigators/Villagers	Meso	Irrigators want to have a storage dam, but villagers want to preserve the land.	No irrigation or loss of land.	Negotiation between RID, irrigators, and villagers before construction. Reasonable compensation and benefit from the project to the villagers.
Water supply/ Villagers	Micro	Excessive groundwater pumping causes land subsidence in the area around the river mouth.	Available water supply or damage from flooding because of land subsidence.	Surface water should be used for DWS. The DWS must be enough for both water supply and industry.
RID/Villagers	Meso	Some villagers do not agree with the construction of flood-protection dike.	Control of freshwater and saltwater area or natural condition	Discussion between RID and villagers about the appropriate design of flood -protection dike.

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Alternative Water-Policy Scenarios Using Integrated River-Basin Modeling: The Brantas River Basin, Indonesia

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Introduction

This paper describes the development of a water-resources optimization-simulation model of the Brantas basin in East Java, Indonesia. The Brantas basin is densely settled, and the water of the Brantas is used intensively for irrigation and, hydropower generation, and for municipal, industrial, domestic and other purposes. Water supply in the basin is now seasonally scarce in many years, and current and potential surface storage in the basin and groundwater are extremely limited. The Brantas is also home to a unique public corporation, Perum Jasa Tirta, which is a prototype River Basin Authority responsible for managing bulk water resources within the basin, maintaining and operating hydraulic infrastructure and helping manage riparian regions of the basin commons. These factors have identified the Brantas as an ideal laboratory in which to develop and test the integrated water-policy-simulation modeling approach we describe here. A map of the Brantas basin is attached as figure 1.

One of the challenges for water management, in the Brantas basin, as elsewhere in the water-scarce world, is to balance the claims of the community of existing water users against increasing new, and often competing, demands; and against the increasingly compelling requirements for water to serve environmental purposes. This model is intended as a tool to assist decision makers, including not only Perum Jasa Tirta but also national, provincial and basin water management councils, government agencies with water-management responsibilities, water users and other stakeholders, in performing this task efficiently and equitably. The goal of this modeling study, and the objective of policy simulation in general, is to provide decision makers with information, albeit "synthetic" information based on simulation models, that will allow them to anticipate the consequences of policies or actions (including the policy of "business as usual") before conducting these policy experiments within society at large, thereby maximizing the probability of successful implementation and minimizing the risk of unforeseen, possibly disastrous consequences.

The development of the integrated policy-simulation model is but one anticipated output of the project titled "Irrigation Investment, Fiscal Policy, and Water Resource Allocation in Indonesia and Vietnam," funded by the Asian Development Bank (ADB) and conducted by the International Food Policy Research Institute (IFPRI) and its Indonesian Directorate General

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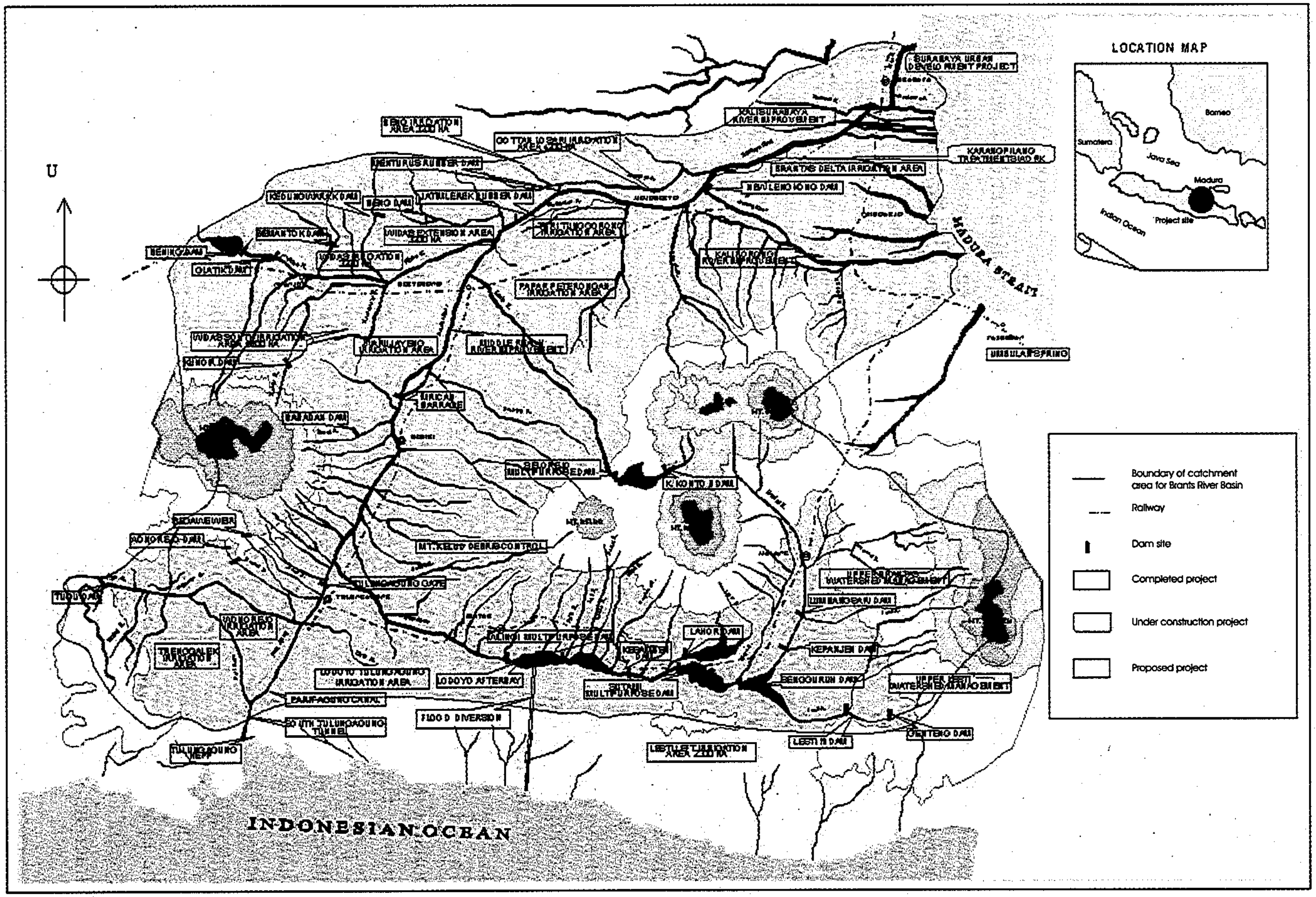
Figure 1. Map of the Brantas basin.



of Water Resources (DGWR). The project consists of three components: a) an assessment of water-allocation mechanisms and institutional structures for river-basin management and effects on irrigation management, b) an assessment of the effects of taxation, pricing policy, and irrigation investment on the incentives for irrigated farming, and c) the development and application of tools and integrated impact analysis to assess the effects of components a) and b). This paper will focus on the third component, although the relevance of policy-simulation output to the broader project goals should be obvious.

A river basin is an extraordinarily complicated system when viewed in purely physical terms; even more so when patterns of settlement, culture and economic activity are taken into consideration. Efforts to capture the richness and complexity of the physical-social-economic environment in model specification predictably encounter the limits posed by available data, and by computing power. A desirable model specification therefore embodies the principle of *Minimum Description Length* that asserts "the best model is the one that is smallest ... including the information to specify both the form of the model and the values of the parameters" (Gershenfeld 1999, 2). The "right" degree of complexity and physical realism is ultimately a subjective judgment, however, and the policy modeler must often strive for relevance at the expense of completeness. The modeler must determine if the marginal increase in the value of model output in policy analysis exceeds the marginal costs associated with increased model complexity, which include those associated with data collection, specification and execution time, and training, transfer and maintenance.

It is therefore reasonable to ask: What are the *essential* components of a useful policy simulation model of the Brantas, those objects or processes that *must* be explicit in the model to achieve relevance and credibility in policy analysis? Similarly, what features of the system can be safely ignored or excluded? A short list of defining attributes of the Brantas hydro-economic system includes the following:

Climatic seasonality. The Brantas experiences a climatic regime characterized by the annual progression of wet and dry seasons, and receives roughly 80 percent of its precipitation in the 5–6 months of the rainy season (December–May). The river discharge is similarly seasonal. As a consequence, the model must have a relatively high resolution in time, since the correspondence of supply to demand in time is a critical aspect of water management in the basin.

Limited storage. Current live reservoir storage in the Brantas is equivalent to around 3 percent of annual Brantas discharges only, suggesting that the potential to manage water crises through reservoir operating protocols alone is limited. However, the available storage is equivalent to 15 percent–20 percent of dry-season discharge, and water scarcity is a phenomenon of the dry season. The implication is that all storage must be represented accurately within the model, including the competing demands and constraints placed on multipurpose reservoirs.

Predominance of paddy cultivation. The agricultural economy of the basin is centered on the cultivation of paddy, nearly all of which is irrigated. Paddy cultivation differs substantially from the cultivation of alternative basin crops (maize, soybean, groundnut, sugarcane), principally in terms of water use. In addition to evapotranspirative demand, paddy requires substantial quantities of water for seedbed development, land preparation, weed suppression, temperature control and other uses. And, unlike many other irrigated crops, technological options for paddy irrigation are limited. Any useful model must be capable of simulating both the hydrology and agricultural economics of paddy cultivation with a fairly high accuracy.

Continuous cropping. A striking feature of irrigated agriculture in the Brantas, as throughout Java, is the continuous cropping calendar. Wet season (November–February) and first dry season (March–June) plantings are spread over 3–4 months each, for reasons relating to water management, labor availability and supply control among other factors. As a consequence, the model must include both crop choice and planting date as decision variables.

Other considerations apply to the model code itself, if it is to prove useful beyond the project time horizon. The code should be transparent: the model structure and parameters should be accessible both to the software engineers who must maintain and modify the model, and to policymakers and managers who require an understanding of the structure of, and assumptions underlying, the model if they are to use it effectively. The code should be flexible and modifiable: it should be possible to update the model in response to changing parameter values (prices, boundary conditions...) and in response to changes in the infrastructure of the hydrosystem itself. These and related factors have guided the development of the Brantas integrated model.

This paper is organized as follows. Section II contains an overview of the model conceptual structure, and of key specification issues related to model functional forms. Section III contains a description of key model components and equations. Section IV describes four model scenarios: baseline, 2020, dry year and increasing water charges to irrigated agriculture. The final section (V) describes some priority policy scenarios.

Some General Considerations Regarding Model Development and Application

Supply Augmentation versus Demand Management, and Distributional Efficiency

Efforts to address the problems of water scarcity or shortage are often conceptualized as falling within one of two broad approaches: supply augmentation and demand management. Supply augmentation includes the construction of reservoirs, tanks, and other regulated surface storage, development of groundwater resources, rainwater harvesting and related activities typically associated with water-resources engineering. Demand management, in contrast, emphasizes changes or modifications in people's behavior with respect to water, typically through the use of incentives and/or penalties. A suitably designed and implemented reward (penalty) structure can encourage efficiency in water use, thereby increasing the *effective* supply, that is, supply relative to demand, via reduction in the demand component. Demand management strategies serve to induce improvements in technical efficiency, including the development of new technologies and processes that require less water to achieve a given level of productivity; reduction of system leakages, and the development of improved water allocation rules, strategies and institutions, such as water markets and water banking.

This description of the integrated modeling approach will focus on demand management, specifically the use of economic instruments as policy tools. It must be emphasized, however, that this modeling approach is also potentially useful in simulating supply-augmentation strategies as well. The model language and structure easily accommodate additions and/or modifications to water-resources infrastructure, and thus the model can be useful in evaluating, for example, the relative effectiveness, in both physical and economic terms, of proposed investments in supply-augmentation infrastructure. The emphasis in policy simulation, however, is on demand-management strategies, and the discussion that follows will focus on the use of economic instruments. It will also focus on irrigated agriculture, but the arguments will be seen to apply to other categories of water demand with little or no loss of generality.

Embedded in the model specification are concepts of efficiency, both physical and economic. The two are closely related—technical efficiency refers to the physical quantity of output obtained per unit of physical input, while economic efficiency refers to the value of output obtained per unit value (or cost) of input. It is clear that the two are not identical, however, since there may be a wide range of physical input combinations that can be used to produce a unit of output in a technically efficient manner, but given differences in input and output costs, only one combination may be the most economically efficient, given market conditions.

There is a more specific definition of economic efficiency, one that is critical to water resources allocation decision making, called *distributional efficiency* or *Pareto efficiency*. Distributional efficiency is based on the fact that a particular resource (such as water) has both an average value and a marginal value in its various uses. The average value is the productive value averaged over the entire range of resource consumed. The marginal value is the productive value of the last (or the next) unit of the resource, evaluated at the current level of use. It is equivalent to the shadow price of the resource in a mathematical programming problem—the change in the objective function resulting from a one-unit change in the binding constraint. Average and marginal values typically differ because each additional or incremental unit of water used is not equally valuable to the firm or consumer—most production (consumption) relationships are characterized by declining marginal productivity (utility). For example, if an irrigated crop is at or near full water supply, any additional water application may have little or no impact on productivity and, hence, on farm income, so that the farmer would only be willing to pay very little for additional water at this point. Or, a household with restricted access to drinking water will be willing to pay considerably more per liter for additional water than a household already enjoying a high level of access and consumption. Differences in the marginal value of water between categories of use and across demand sites within the basin define the opportunities for the improvement of distributional efficiency, and it is fair to describe this integrated policy simulation model as marginal-value-driven, subject, of course, to a wide range of constraints, both physical and institutional.

Responses to Changes in Water Price (Quantity)—The Importance of Functional Form

Faced with an increase in the supply price of water, or an absolute change in the quantity of water available (as in a drought year), farmers have five basic strategies available for adapting to changing circumstances:

1. *They can use less water.* If water prices increase, farmers may choose to apply less than the full crop-water demand. This will result in a reduction of yield, but the farmer may be operating in a range of yields within which this yield reduction is proportionally less than the decrease in water use.

2. *They can switch to less-water-consumptive crops.* In the Brantas, for example, maize and paddy are roughly equally profitable at current input and output prices, but maize requires far less water per kilogram of yield. The price (or availability) of water may be the deciding factor.

3. *They can alter the time of planting* in an attempt to reduce irrigation demand, by exploiting seasonal variation in effective precipitation, evapotranspiration and possibly in the cyclic demand of competing water-using industries (e.g., sugar processing).

4. *They can substitute other inputs for water.* Increases in complementary inputs, including labor and fertilizer, can partially offset yield loss due to water reduction, although the range of substitution may be limited, particularly for crops such as paddy.

5. *They can increase the efficiency by which they use water.* This can include improved management, or investment in alternative, water-saving irrigation technologies.

Note that the first four adaptations can be implemented in the short run, in response to either unexpected or transient circumstances, while the fifth embodies adaptations that may occur in the short run (management) or the long run (investment).

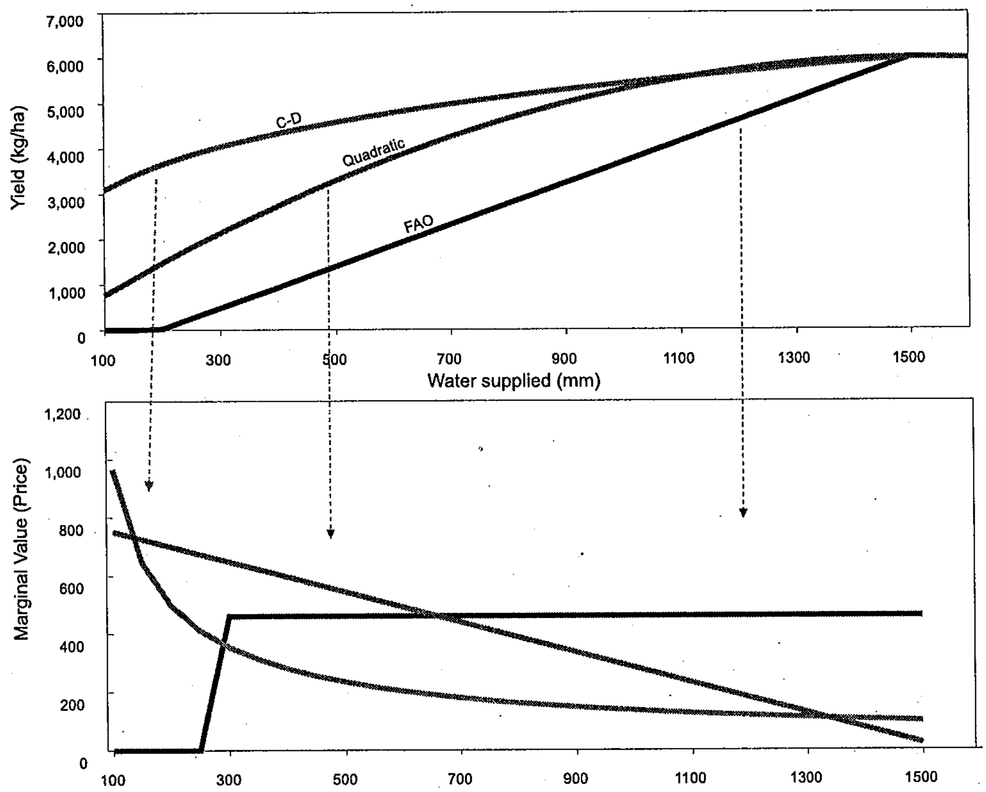
We would like to be able to simulate each of these types of responses within the model, to obtain maximum sensitivity both to economic policy instruments and to changes in environmental circumstances. This forces us to give careful consideration to the functional forms by which we represent water-production and consumption processes. When water is used as an intermediate input to a final output, as in agriculture and many industries, we employ a technical production function—a mathematical specification of the relationship between input and output quantities. When water is itself the final (consumed) product, as in domestic uses, we use an alternative approach based on willingness-to-pay functions and consumer surplus.

A variety of functional forms have been proposed to quantify the relationship between water as a quantitative input and resulting crop yield. Single-input (water)–single-output models include the FAO yield response coefficient method (Doorenbos and Kassam 1986), which specifies a linear relationship; and exponential models such as Bouman and Tuong (2001). Multi-input–single-output models include Cobb-Douglas and quadratic functions (Moore et al. 1993). In these and related models, water is one of multiple inputs, which can include land, labor, fertilizer and technology. Cobb-Douglas and quadratic forms are nonlinear. Other multi-input functions, such as Dinar-Lehey allow the simulation of the impacts of input water quality as well.

In evaluating the suitability of each functional form for simulating the (above) five responses, we offer the following observations. In regard to the substitution of other inputs for water (point 4), multi-input models are clearly superior, since rates of technical substitution are explicit and these relationships are estimated directly from observed data. It is possible to model substitution using single-input approaches, provided the "target" or maximum yield (corresponding to full water supply) is itself specified as a function of the other inputs, but in this case the rates of substitution have not been estimated directly. In regard to cultivation timing strategies (point 3), any of the approaches described above would appear suitable, since choice of planting time affects the water-demand level rather than output.

However, the evaluation of strategies 1 and 2 (reducing water supply, switching to alternative crops) requires particular care. All of the functional forms described will permit this kind of simulation, but the sensitivity with which they do so varies widely. To illustrate this point, consider figure 2, which depicts both output response to water application (upper) and corresponding marginal value of water (lower). Coefficients have been constructed such that a given quantum of water (1,500 mm) results in roughly the same maximum yield (6,000 kg/ha) in each production function for this hypothetical paddy crop.[4]

Figure 2. Output response to water application (upper) and corresponding marginal value of water (lower).



[4]Other factors of production, such as labor, fertilizer and mechanical power are assumed implicit in these water-production relationships.

The lower portion of the graph depicts the marginal value of water in irrigated rice production, obtained by multiplying the derivatives of the production functions (upper graph) by the crop output price, which in this illustration has arbitrary units. We note that the FAO (linear) function has a constant derivative, the quadratic function a linear derivative and the Cobb-Douglas a convex derivative. Now, assume that a volumetric water charge is enforced, and consider an increase in this price (lower graph). Since an economically rational farmer will not purchase water past the point where the marginal value of the water equals its price, farmers facing both quadratic and Cobb-Douglas production relationships will reduce the amount of water purchased until the marginal value is again equal to the new (higher) price. The degree to which water use will be decreased is seen to depend on both the level and the shape of the marginal-value curve within the region determined by the price change. In this case, the price increase induced a larger response on the Cobb-Douglas, indicating that, in terms of this functional relationship, yield was originally in a region relatively insensitive to (small) changes in water supply.

For the quadratic, the quantity response to a price change of a given magnitude is invariant to location, since the derivative is linear. But, for the linear FAO-type function, the marginal value is a constant, and a farmer operating on a linear-production relationship has no incentive to reduce water use in response to a price increase, that is, until the price rises above his average value of water, at which point his response will be to switch to another crop rather than lose money. The full range of responses available under nonlinear production relationships is not available to him, at least within the context of this formal analysis.

This is not to argue that the water-production functional form should be determined on the basis of desired model behavior—functions are selected because they fit the data. However, experience has shown that, given the "signal-to-noise ratio" inherent in most production data sets, various alternative functional forms may fit the data equally well within the range of interests. We argue that, given a choice, a functional form that captures the declining marginal productivity of water should be used, since it is best suited to price-driven policy simulation.

Model Structure and Basic Equations

General Description of the Model

The policy-simulation model developed for the Brantas is the integration of a network-flow hydrologic model with physical-process simulation models of irrigated-agricultural production, hydropower generation, municipal (domestic) and industrial demand, and with economic relationships driven primarily by the relative prices and values of water in its respective uses. The resulting system of equations is linked to large-scale nonlinear optimization algorithms, which locate combinations of the decision variables that are mathematically optimal according to the structure of the objective function, the form of which is determined by the specific objectives of policy simulation. It is therefore described as a *river basin simulation-optimization model*. The integrated model differs from a conventional network-flow model in many key respects. Demand for water by sector and by location are endogenous to the model and represent the interaction of technical/economic water production or utility relationships in agriculture, industry and households with assumptions concerning the structure of water pricing, entitlements, public institutions, social custom and law.

The Brantas basin model has evolved from the prototype simulation-optimization model of the Maipo basin, Chile, described elsewhere. The conceptual and technical basis for integrated basin-scale modeling is described in the state-of-the-art review by McKinney et al. (1999). Additional background information on the Brantas basin physical setting and model development is found in Rodgers et al. 2001.

The model is coded in the high-level programming language GAMS (General Algebraic Modeling System), which was developed to provide an open, flexible architecture for mathematical-programming problems (Brooke et al. 1998). GAMS code is portable, self-documenting and readily modified. One can, for example, easily add a new irrigation system, reservoir, or hydropower plant to an existing model, or change the properties of such a model element, since the code is visible and accessible, and the structure of equations is independent of the number of set members, or where they spatially occur within the basin system. GAMS, in turn, is linked to one of two large-scale nonlinear optimization solvers, CONOPT2 or MINOS5. CONOPT2 is currently our solver of choice.

The model is organized around the water (or crop) year, beginning in October and ending in September. Model timesteps are 10-day periods, approximately: for each month, period 1 = 1:10 days, period 2 = 11:20 days and period 3 = 21: end of month (EOM). The model is "circular" in the sense that crops planted near or at the end of the crop year (period 36) are "wrapped around" to the beginning in a seamless cycle. In the following sections, individual model components are described in greater detail.

Network-Flow Model Structure and Inputs

The structure of the Brantas network-flow hydrologic model is based on the configurations of two reservoir operations models, WRMM and RBAM (Optimal Solutions Ltd. 2000), which are currently maintained at Perum Jasa Tirta. The network-flow model consists of reaches, which represent points of inflow to the system (reservoirs, river reaches, etc.), points of water storage, control, diversion and abstraction (dams, reservoirs, barrages, weirs, etc.), and demand sites (irrigation, municipal, industrial, hydropower, etc.). Each of these elements is linked via spatially permissible flow paths, which can represent natural or artificial channels. Inflows to the system, including precipitation, are model boundary conditions; and storage, channel and spillway capacities are model constraints. A schematic representation of the flow network is given in figure 3, and model elements are summarized in table 1.

Figure 3. Brantas river-basin modeling schematic.

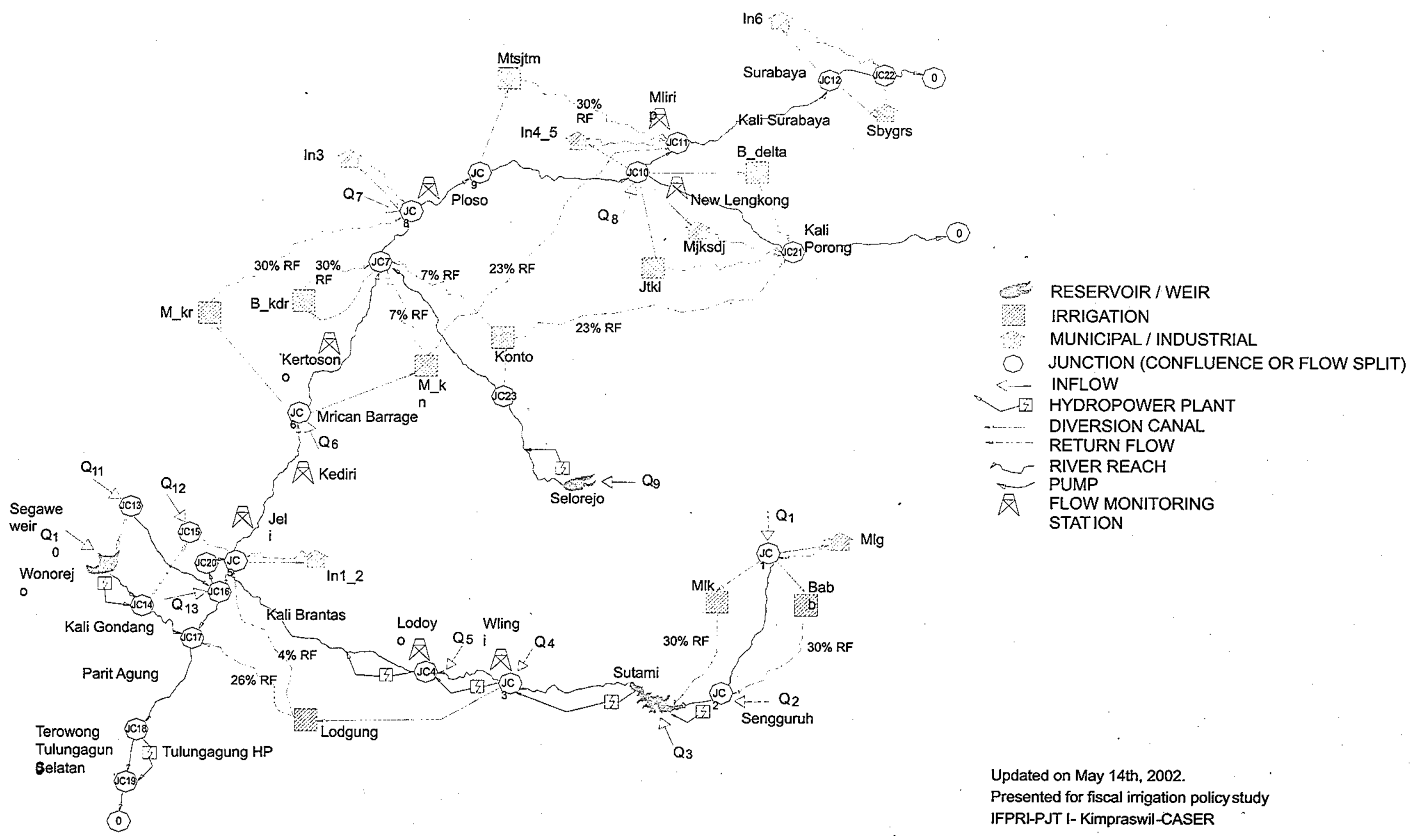


Table 1. Integrated model components.

Model Component	Current	Planned	Comments
Reservoirs	3	5	320 MCM live storage
Reservoir hydropower plants	3	5	116 MW generating capacity
Run-of-river hydropower plants	4	4	124 MW generating capacity
Irrigation systems[a]	10 (14)	15 (20)	> 95,000 hectares
Municipal demand sites	3 (5)	na	Excludes groundwater, springs
Industrial demand sites	4 (7)	na	Excludes groundwater, unauthorized abstractions
River reaches	23		
Inflow records	13		MCM/year
Total network flow elements	63		
Total decision variables	>24,000		>90% in irrigated agriculture
Total equations	20,000		>90% in irrigated agriculture

Note: na = Data not available.

[a]Numbers in parentheses refer to the number of physical sites, as distinct from the number of model elements. When two or more sites abstract water from, and return flow to, a common model reach, they can be modeled as a single system.

The water balance on each network component (river reach, reservoir) can be generalized as:

$$\sum Q_{in} + I_i + \sum R = \sum Q_{out} + \sum A + \frac{\Delta S}{\Delta t} \qquad (1)$$

where, Q_{in} inflow from upstream reaches, reservoirs, power plants
I diffuse inflow from runoff and groundwater discharge (may be negative)
R return flow from demand sites (irrigation, industry, etc.)
Q_{out} outflows to downstream reaches, reservoirs, power plants
A abstractions to demand sites
S storage (reservoirs only)
t model timestep

The integrated modeling approach as specified for the Brantas does not include an explicit rainfall-runoff component.[5] Inflows entering the system at reservoirs, channel reaches or aquifers are therefore one set of boundary conditions for the model, reflecting historical patterns of precipitation and discharge.[6] To provide these boundary conditions it is necessary to develop "natural" flows for each appropriate node or component comprising the model. Natural flows are those flows that would be observed in the absence of any artificial water regulation or manipulation, including storage, abstraction, discharge or redistribution outside of the natural-flow network. Natural flows are required for several reasons, perhaps the most important of which is to ascertain the true incremental flow contribution from each increment of drainage area as defined by the location of model nodes. Three discrete sets of estimated natural flows were made for numerous locations within the Brantas basin by JICA (1998), SRPCAPS (1999) and Optimal Solutions, Ltd. (2000), and they have been adapted selectively for the present study.

Natural flows evaluated at exterior nodes are simply measured discharges at these locations, since it is assumed that there is no significant regulation upstream of these points. For all interior nodes, natural flows must be reconstructed by water balance. For a generic node i (e.g., a weir location) connected upstream to a single node (i-1) the calculation for each timestep takes the general form (time subscripts implicit):

$$Q^n{}_i = Q^n{}_{i-1} + \sum_{i-1}^{i} A - \sum_{i-1}^{i} R + \sum_{i-1}^{i} \frac{\Delta S}{\Delta t} + Q^{in}{}_i \qquad (2)$$

where,	$Q^n{}_i$	natural flows at node i	(m^3/sec)
	A	abstractions between nodes (i-1) and i	(m^3/sec)
	R	return flows	(m^3/sec)
	S	changes in storage	(m^3)
	t	model timestep	(sec)
	$Q^{in}{}_i$	inflow between nodes (i-1) and i, added to modeled flows at node I	

Natural flows are calculated recursively from upstream (exterior) nodes proceeding downstream. Where storage reservoirs are present, net evaporation must also be included in natural flow calculations.[7] SRPCAPS (1999) in addition calculated the implicit fraction of precipitation constituting inflow (Q^{in}) for each sub-catchment. A certain degree of consistency across sites is anticipated, and deviations from this pattern (roughly 50% of precipitation enters the flow system, varying by altitude, soil type, and ground cover) were used to identify and diagnose potential errors in the flow statistics.

[5]Rainfall-runoff modeling may be eventually required to augment existing inflow data, particularly for tributary subsystems.

[6]Alternative climatic regimes can be modeled as well.

Calculating Irrigation System Efficiency, Return Flows and Depletions

We are interested in whole-basin efficiency, so that we must account for system offtakes, return flows, and depletions. It is therefore necessary to evaluate the relationships between diversion (abstraction) at the system level and the resulting supply available at the crop level; and between offtakes, return flow, and corresponding depletions. We consider three components of irrigation system efficiency and their relationship to return flows. Following Xie et al. (1993) we define:

Conveyance efficiency (Ec) as the ratio of the volume of water diverted to the main canals from all sources (Ws) to the volume delivered to the distribution network (Wd):
Ec = Wd/Ws

Distribution efficiency (Ed) as the ratio of the volume of water delivered to the field (Wf) to the volume delivered to the distribution network:
Ed = Wf/Wd

Field application efficiency (Ef) as the ratio of water beneficially used by crops (Wc) to the volume delivered to the field:
Ef = Wc/Wf

The SRPCAPS (1999) study team evaluated water-delivery records for the major Brantas irrigation schemes, and derived estimates of conveyance efficiency (Ec). SRPCAPS (1999) also recommended a value of 0.9 as appropriate for distribution efficiencies (Ed). We have estimated field efficiencies (Ef) based on a formalism suggested by Bernardo and Whittlesey (1989). This formalism is based on the observation that "...nonproductive losses generally increase as the point of maximum ET (evapotranspiration) is approached, leading to a diminishing return from water application" (p.2). There are other mechanisms at work as well, including the properties of soil-moisture release curves. We use an estimate of the form:

$$E_f = \exp^{\left\{-k\left(\frac{WS}{WD}\right)\right\}} \qquad (3)$$

where,

	WS	water supplied to crop for beneficial use, irrigation + precip
	WD	water demand at crop level
	k	an empirical parameter

The value of the parameter k is set such that the field application efficiency at supply equal to 100 percent of beneficial water demand is 0.9, indicating that one must supply approximately 1.1 mm of water for every 1 mm of beneficial demand at full supply. The resulting efficiencies used in the model baseline are summarized in table 2.

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[7]Brantas reservoir outflows are typically corrected for water-surface evaporation, so this step is redundant in the current model.

Table 2. Efficiencies of Brantas basin irrigation systems.

System name	Area (ha)	Conveyance efficiency (Ec)	Distribution efficiency (Ed)	Field application efficiency (Ef)	Project efficiency Ec*Ed*Ef
Brantas atlas + Bawah	3,130	0.65	0.90	0.90–1.0	0.53–0.59
Molek	3,984	0.63	0.90	0.90–1.0	0.51–0.57
Lodoyo-Tulungagung	12,298	0.56	0.90	0.90–1.0	0.45–0.50
Mrican Kanan	16,344	0.60	0.90	0.90–1.0	0.49–0.54
Mrican Kiri	12,546	0.72	0.90	0.90–1.0	0.58–0.65
Brantas Kiri-Kediri	534	0.62	0.90	0.90–1.0	0.50–0.56
Menturus-Jatimlerek	5,093	0.76	0.90	0.90–1.0	0.62–0.68
Jatikulon	619	0.65	0.90	0.90–1.0	0.53–0.59
Brantas delta	26,718	0.67	0.90	0.90–1.0	0.54–0.60
Konto systems	13,812	0.65	0.90	0.90–1.0	0.53–0.59

The Unified Economic Objective Function

The objective function of the integrated model is the combined, net water-generated revenue function for the basin. By expressing all objective-function linear components in a common metric (Rp per year), we avoid the need for the weighting schemes commonly used in multiobjective programming, which contains an unavoidable element of subjectivity. The unified objective function takes the generic form:

$$Max\{Z\} = \sum_{irr} Z_{irr} + \sum_{ind} Z_{ind} + \sum_{mun} Z_{mun} + \sum_{hydro} Z_{hydro} \tag{4}$$

where, *irr, ind, mun, hydro* refer to net profits (benefits) over irrigated agricultural, industrial, municipal and hydroelectric demand sites, respectively. Currently, water-quality objectives or standards are also incorporated into the model directly as minimum flow constraints.

The terms in the objective function take the general forms of *profit functions* (used for irrigated agriculture and hydropower generation) emphasizing the contribution of water as a priced input in the production of an output with market value; and *benefit functions* (used for municipal and industrial demand[8]) which describe the value of water in uses such as domestic consumption where no output having market value is produced, but where use is nevertheless a valuable activity. The generic form of the profit function is:

[8]The benefit function is used for industrial water demand because the specific forms of industrial water-production functions are not known.

$$Z_i = \left(y_i(w_i) \cdot Py_i - w_i \cdot Pw\right) \tag{5}$$

where,	Py	price of output(s) y
	y(w)	output quantity y, a function of w
	w	quantity of water consumed
	Pw	unit price of water
	i	index of demand site

The generic form of the benefit function is:

$$Z_i = \left(\int_{w0}^{w} WTP(w) - w \cdot Pw \right) \tag{6}$$

where, WTP(w) willingness-to-pay function for water
(other terms as above)

Calculating Irrigated Agricultural Output and Water Demand

Pursuant to the previous discussion of functional form, the following agricultural water production functions are understood to be provisional. We anticipate using either Cobb-Douglas or quadratic multi-input production functions once the data required to estimate functions of these forms has been fully processed and evaluated.

In the Brantas basin, paddy is the most important crop, from the perspectives of land use, water use, farm economy, and dietary composition. Bouman and Tuong (2000), on the basis of an analysis of over 30 studies of rice yields obtained under controlled conditions, have proposed a paddy water production function of the general form:

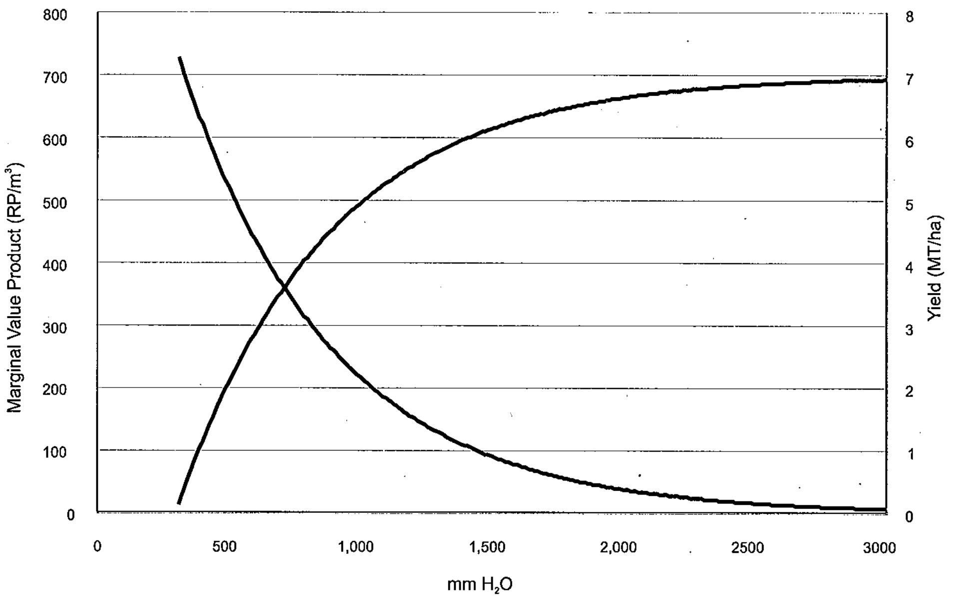
$$Y_A = Y_P \cdot \left(1 - e^{\{-\beta \cdot (W - W_0)\}}\right) \tag{7}$$

where,	Y_A	actual yield	(kg/ha)
	Y_P	potential or non-water limited yield	(kg/ha)
	β	water-yield response coefficient	(parameter)
	W	water application	(mm)
	W_0	no-yield water application threshold	(mm)

The Bouman-Tuong function, and marginal value of water in paddy production are plotted in figure 4. We can see that there is an extensive region over which significant changes in water application have relatively little effect on yield, resulting in very low levels of marginal water value. This suggests that the demand for water for paddy irrigation will be highly sensitive to any price the farmers must pay for water, particularly within these ranges of application.

FAO methodology is based on the yield response coefficient (K_Y) method, described in FAO 33 1986. The K_Y method describes the fractional reduction in yield relative to its potential at full water supply (Y_P) resulting from a fractional reduction in actual evapotranspiration relative to reference crop evapotranspiration (ET_0):

Figure 4. Exponential water production function and marginal value of water.



$$\left(1-\frac{Y_A}{Y_P}\right)=K_Y\cdot\left(1-\frac{ET_A}{ET_0}\right) \qquad (8)$$

where,			
	ET_A	actual evapotranspiration	(mm/day)
	ET_0	reference evapotranspiration	(mm/day)
	Y_A	actual yield	(kg/ha)
	Y_P	potential yield	(kg/ha)
	K_Y	crop yield coefficient	(unitless)

This functional form is linear, as noted above, which severely restricts the model as currently (provisionally) specified in evaluating the fine trade-offs resulting from modest changes in the (assumed) volumetric price of water that farmers face.

Calculating Hydropower Water Demand

The Brantas basin presently contains nine hydropower facilities, of which eight are currently operating. They are categorized either as reservoir facilities, for which effective head varies with the extent of reservoir storage, and run-of-river stations, for which head is essentially constant. Within the model, power generation is estimated using a standard approach based on effective hydraulic head, turbine-discharge volume, and efficiency. The general form of this equation is (Mays and Tung 1992) as follows:

$$P = C \cdot \gamma \cdot Q \cdot h \cdot \eta \qquad (9)$$

where,	P	power generated	(kWh)
	C	numerical coefficient to conserve units	
	γ	unit weight of fluid	(N/M^3)
	Q	rate of discharge	(M^3/sec)
	h	effective energy head	(M)
	η	turbine efficiency	

Q is a decision variable, and h is a state variable functionally related to reservoir storage. Power generation is a nonconsumptive use of water, and does not degrade water quality, although the extent and timing of power demand can, and does, conflict with the demand for water in various consumptive uses, at least during certain periods. Hydropower represents roughly 16 percent of the installed generation capacity in the Brantas basin.

Calculating Municipal (Domestic) Water Demand

The conceptual basis upon which municipal, or domestic demand is calculated is different from that of agricultural demand, since the water diverted and consumed by households is not an input to a production process as such, but rather an end use that serves a variety of needs, including drinking, cooking, washing and sanitation, which are not market transactions. The approach we use is to estimate the *consumer surplus* associated with each level of water use. This is the level of benefit or utility that a household receives from a given level of water consumption, which is in excess of what they must actually pay for the water. It is revealed through a stated *willingness to pay*, as recorded in a sample survey.

To obtain the consumer surplus estimate, first, we estimate a conventional log-linear demand function using data from a recent household survey of municipal water users: water demand (W) is found to be an increasing function of income and a decreasing function of price, as consistent with economic theory:

$$\ln(W) = \alpha + \beta \cdot \ln(Y) - \varepsilon \cdot \ln(P) \quad (10)$$

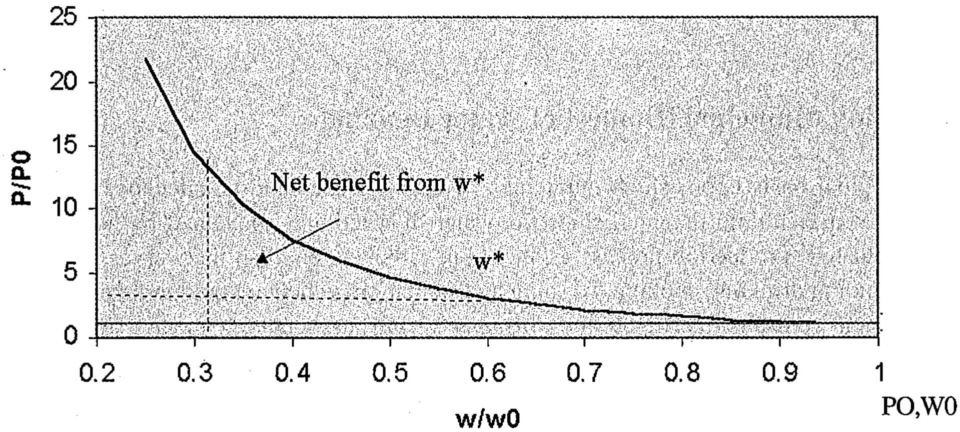
where, W = quantity of water demanded in M^3 per capita per 10-day period
Y = income in 1,000's Rp per capita per month
P = price of water in Rp per M^3

In our sample, **a** (intercept) = -1.067, **b** (elasticity with respect to income) = 0.4817 and **e** (elasticity with respect to price) = 0.478.[9] Next, we invert the equation to obtain price as a function of quantity: this is the *inverse demand or willingness-to-pay curve* which in real-space takes the form:

$$P = e^{\left(\alpha/_{\varepsilon}\right)} \cdot Y^{\left(\beta/_{\varepsilon}\right)} \cdot W^{\left(-1/_{\varepsilon}\right)} \quad (11)$$

The next stage is to identify a minimum acceptable level of consumption, W_0. This can be done either on the basis of the household sample-survey results, or on the basis of internationally accepted norms. We can now estimate per capita consumer surplus as a function of water consumption (w) by integrating the inverse demand function between w_0 and w, and subtracting the price actually paid. The estimation of consumer surplus is illustrated in figure 5.

Figure 5. The estimation of consumer surplus.



[9] ε is actually negative, since quantity demanded falls as price increases, but we report the absolute value of the coefficient.

$$CS(w) = \frac{e^{(\alpha/\varepsilon)} \cdot Y^{(\beta/\varepsilon)}}{\left(1 - \frac{1}{\varepsilon}\right)} \cdot \left\{ w^{(1-1/\varepsilon)} - w_0^{(1-1/\varepsilon)} \right\} - w \cdot Pw \tag{12}$$

It is important to recognize that this estimate of consumer surplus is not directly comparable to the value of water in agricultural production, since the conceptual bases for estimation differ. In particular, the base level W_0 is more a mathematical necessity than a measurable quantity. However, water reallocation within the model is driven not by consumer surplus itself, but by the marginal willingness to pay for water, which is more directly comparable to the marginal-value productivity of water in an agricultural-production function.

Calculating Industrial Demand

The calculation of economic demand for water by industrial users in the Brantas is corr ated by several factors. First, we have no reliable information on the internal economics of water use by Brantas industries. In addition, commercial water users in the Brantas consist of many discrete industries—sugar processing, paper, leather and food processing—each of which uses water as a productive input in unique ways. A production-function approach to water demand (which is the conceptually correct approach given that water is an input to a marketed end product) is therefore impracticable, at least in the absence of new data. Second, we do not have survey or other data revealing willingness to pay by industry for various increments of water delivery, as we do for domestic use. In addition, the price at which Perum Jasa Tirta provides water to industrial users has changed very little over the last decade; thus the empirical relationship between price and quantity provides very little information on the underlying economic-demand relationships.

We have taken a provisional approach to the estimation of industrial water demand, which rests upon several pieces of information that we do possess. The first is the estimated average value-added associated with each cubic meter of water used in industry, for a recent year (1996). JICA calculated water's share of total input costs, and assumed that the share of value-added was proportional. The resulting estimate of water's average net productivity in industry is Rp 176/m^3 in 1996, or Rp 360/m^3 in 2000 (adjusted using the industrial deflator). We also know that Brantas industries have improved their water use efficiency in recent years, and have consequently reduced their purchases of water from PJT (internal communication). It appears reasonable to assume that current levels of water use are therefore demand-constrained. This would suggest, in principle, that industries are using water roughly to the point where the marginal value product of water equals the price they pay for water, P_W, currently Rp 51/m^3. Finally, we know how much water is actually being abstracted by industries at various locations throughout the basin.

Given the observed level of water use, and of average and marginal values, we can develop a synthetic willingness-to-pay curve in the following way: first, we reasonably assume that the demand for water is inversely related to price, reflecting declining marginal productivity:

$$\ln(W) = \alpha - \varepsilon \cdot \ln(P_W) \tag{13}$$

Since this curve, by assumption, will pass through the point (W, P_W), where W refers to the current level of use, there will be a unique value of **a** for each value of **e**. A review of some recent literature on industrial demand for water (Wang and Lall 1999; Renzetti 1992) suggests that ?, the demand elasticity of water with respect to price has an absolute value in the range 0.5 to 1.0. It is likely to be higher in regions where industries are relatively inefficient in water use; and relatively inelastic where they are highly efficient. Since Brantas industries have recently improved their water use efficiency, it was assumed that elasticities are in the range 0.5 to 0.75 in absolute value. For a given value of **e**, the log intercept (**a**) is easily obtained from equation (14) given the known or assumed values of W and P_W.

The final stage is to find the base water use, W_0, below which no benefits occur. The appropriate value of W_0 is that which corresponds to an average surplus value equal to the JICA 1997 estimate of 360 Rp/m³:

$$\left[\frac{e^{(\alpha/\varepsilon)}}{\left(1 - 1/\varepsilon\right)} \cdot \left(W^{(1-1/\varepsilon)} - W_0^{(1-1/\varepsilon)}\right) - W \cdot P_W\right] \cdot \left(\frac{1}{W}\right) = 360 \tag{14}$$

This expression can be rearranged to show that W_0 is always a constant fraction of W for a given value of **e**. This allows the synthetic demand curve to be scaled to varying levels of water use while preserving the marginal and average productivity of water. Values of (W_0/W) for typical values of elasticity (e) are: **e** = -0.5, W_0/W = 0.1104; **e** = -0.6, W_0/W = 0.02617; **e** = -0.75, W_0/W = 0.0076. In current model runs, we use an elasticity (e) of –0.5.

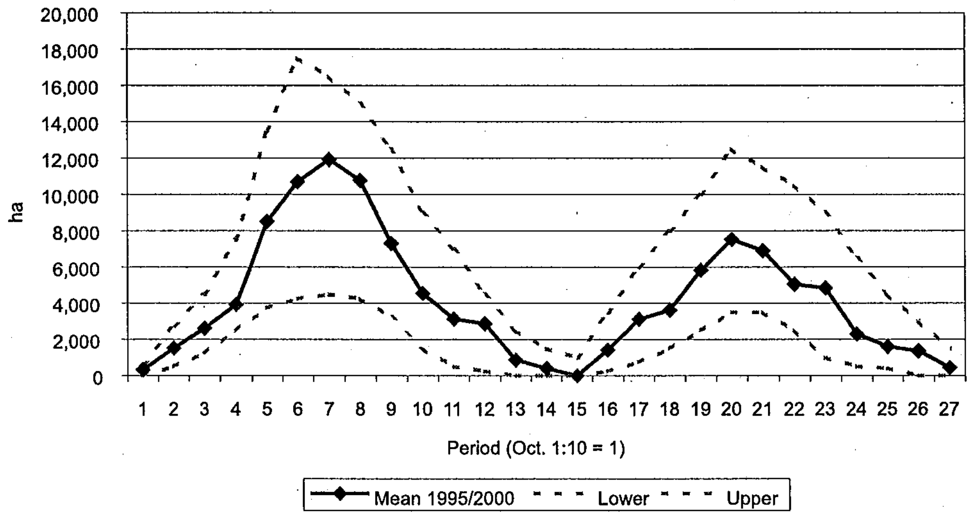
Constraining the Model

There are many classes of constraints in the model, reflecting the physical capacities of infrastructure, such as the live storage capacity of dams, the conveyance of channels, and the design irrigated area within a system. Even within these constraints, found primarily in the network-flow portion of the model, the solution space (set of feasible combinations of decision variables) is unmanageably large. The largest numbers of free (decision) variables occur within the irrigation modules. These include area by crop and planting date (> 1,500) and water supplied to each crop in each period (> 22,000). To reduce this sample space, we enforce two sets of constraints, one set at the system level and another at the basin level.

The system-level constraints require that for each major crop type, there are minimum and maximum planting requirements by season. Minimum requirements are intended to ensure that at least a fraction of the historical level of cultivation is maintained through the range of scenarios. This is understood to reflect the nature of traditional preferences, acquired expertise in cultivation and risk aversion that often lie outside the realm of purely price-driven calculation. These constraints are set at around 40 percent of average cultivation levels. Maximum constraints, in contrast, serve two functions. The first is land suitability: all land within a given irrigation system may not be simultaneously suitable, e.g., for paddy cultivation, which requires (or prefers) soils of high clay content to minimize percolation, and root crops that require more well-drained soils for optimal yields. The second function is supply control: there is an inverse relationship between aggregate supply and market (farm-gate) price, so that overproduction of crops would lead to the depression of prices. As the current configuration of the model does not specify farm-gate prices endogenously, planting limits provide alternative constraints against oversupply.[10]

The basin-level constraints are designed primarily as supply control as well. These constraints stipulate that the sum of all crops (by type) established within each of the 36 model periods falls within bounds defined by historical patterns of cultivation. The levels of these constraints, plotted with historical levels of cultivation, appear in figure 6.[11] It is seen that these constraints are not overly restrictive. It is also important to note that both sets of constraints apply to linear combinations of individual decision variables, thereby retaining many degrees of freedom—no individual variables are subject to *ad hoc* constraints within the model.

Figure 6. Global planting constraints on paddy.



[10]We have run versions of the integrated model with endogenous price specifications, which achieve the desired objective of supply control effectively, but the addition of the endogenous price equations increases execution time by a full order of magnitude.

[11]Sugarcane is similarly constrained.

Solving the Model

Optimization modelers will typically initialize the values of decision variables before attempting an optimization, in order to move the optimization search immediately to a subregion of the solution space within which the optimal solution is believed to lie. This will reduce the time required for computation, which can be considerable, but it may also bias the model solution toward a particular local (as opposed to global) value. We have discovered that, due to the extremely large number of decision variables (24,000) and equations (20,000), and due to the numerous nonlinearities in the model equations, GAMS will typically fail to find a feasible solution when initialized and run in this manner. We have developed an alternative solution method based on a four-stage optimization, where an increasing number of decision variables are solved in each stage. No initializing values are used; all decision variables start at system defaults. The step-wise procedure is as follows:

1. Optimize the network-flow components (including hydropower, municipal and industrial demand as active decision variables) while holding irrigation water abstractions by system to fixed, historical levels. This gives us initial values of all decision variables associated with the flow network, but excluding cropping and irrigation decisions.

2. Optimize crop-planting decisions across all irrigation systems, again holding total water abstractions to the same constant value as in phase 1, which require full water supply to each crop. This gives us initial values of crop area allocations by planting date, an important decision variable.

3. Re-optimize irrigation system output, again holding system abstractions constant, but now allowing decisions on field-level water allocation by crop and period. This is by far the largest class of decision variables in the integrated model, containing roughly 22,000 of the 24,000 total decision variables.

4. Finally, link the network-flow and irrigation system equations and solve the entire system, with all decision variables subject only to the model physical and institutional constraints.

The technique is time-consuming, with an average run cycle requiring between 7 and 24 hours on a standard PC (Pentium III, 1 GHZ). However, the solutions have the desirable property of not being biased by the initial values selected by the modeler.

Some Preliminary Model Results

In this section, we describe the results from some preliminary model runs. These runs are primarily diagnostic. That is, while we may obtain some useful insights relevant to policy design from these runs, we have performed them primarily to diagnose model performance and sensitivity relative to changes in parameter values. In addition, the final model specification used for policy analysis will contain updated specifications of crop water production functions, for reasons discussed earlier, which are likely to have a substantial influence on the model response to changes in relative price. We will also improve our specification of industrial demand, although the form of this modification will depend on the data subsequently available.

Scenarios and Data

The following scenarios were run. Details are summarized in table 3.

Baseline. Most boundary conditions at 1995–2000 values; water-charge prices at current (PJT) levels; municipal demand based on estimated demand model parameters, with an upper limit of 500/l*ca*day; industrial demand by synthetic WTP as described above.

2020. This scenario is based largely on projections made by SRPCAPS (1999) except as noted: climatic boundary conditions at baseline levels; irrigation-system areas adjusted downward due to urban infringement, which is anticipated to affect the Brantas delta irrigation systems most profoundly; increases in municipal demand driven by population growth and increase in service coverage; industrial demand growth as estimated by SRPCAPS; and loss of reservoir capacity as estimated by JICA (1998).

Dry year. This scenario is based on crop year Oct. 1996–Sept. 1997, which was one of the driest in the last 20 years. Precipitation and system inflows are the historical flows for this period. All other conditions are as in the baseline scenario.

ISF. A series of scenarios using the baseline values of all parameters and boundary conditions, to which a volumetric water charge (ISF) was introduced, and systematically increased from 0 Rp/m^3 to 35 Rp/m^3 in 5 Rp/m^3 increments. The 35 Rp/m^3 ceiling was chosen because it corresponds to the JICA (1998) estimate of full capital and O&M cost-recovery level, approximately.

In all scenarios, the following crop types and durations were used. Durations were based on an analysis of cropping patterns in the Brantas irrigation systems during five recent crop years (1995/96–1999/00), and verified on the basis of the 1999/2000 farm sample survey (given below):

Crops	Paddy	120 days	(20 days nursery, 100 after transplant)
	Maize	90 days	
	Soybean	90 days	
	Groundnut	110 days	
	Sugarcane	365 days	(does not include initial land preparation)

Other parameters related to irrigated cropping—including mean and maximum yields, input and output prices, intensity of fertilizer and pesticide application, labor intensity, use of machinery, and water use—are based on plot-level data collected by field teams from the Center for Agricultural and Socioeconomic Research (CASER) during late 2000–early 2001. The sample consisted of 160 farm households from each of four irrigation systems chosen to represent

Table 3. Summary of model scenario assumptions.

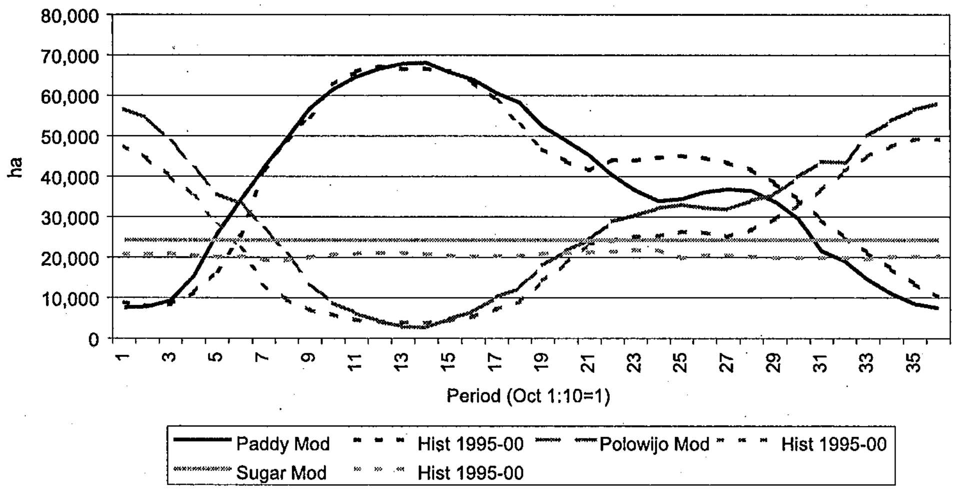
Parameter	Baseline	2020	Dry year	Water charge
Precipitation	Effective, 80% exceedance probability, 1970-1999	Effective, 80% exceedance probability, 1970-1999	Effective, crop year 1995-1996	Effective, 80% exceedance probability, 1970-1999
Inflows	$8{,}030*10^6$ m^3	$8{,}030*10^6$ m^3	$6{,}200*10^6$ m^3	$8{,}030*10^6$ m^3
Irrigated area	95,038 ha net	82,087 ha net	95,038 ha net	95,038 ha net
Municipal demand	1,200,000 served	3,100,000 served	1,200,000 served	1,200,000 served
Industrial demand	$121.5*10^6$ m^3 base	$231.3*10^6$ m^3 base	$121.5*10^6$ m^3 base	$121.5*10^6$ m^3 base
Reservoir capacity (active storage)	$320*10^6$ m^3	$308*10^6$ m^3	$320*10^6$ m^3	$320*10^6$ m^3
Water charges	Irrigation 0 Rp/m^3 Municipal 35 Rp/m^3 Industrial 51 Rp/m^3 Hydro13.6 Rp/kKWhH	Same as base	Same as base	Irrigation fees: 0:5:35 Rp per cubic meter
Water entitlement	200 literes per day per ca, domestic	Same as base	Same as base	Same as base

different agro-ecological settings within the basin: Lodo Agung in the upper region, Mrican Kiri and Kanan in the middle and Porong canal in the Brantas delta. In each system, 3 tertiary blocks were chosen on the basis of water-delivery infrastructure and composition of cropping, and 40 farm households were selected from within each tertiary block, for a total sample size of 480.[12] It should be noted that values of most parameters differ across irrigation systems, contributing in turn to differences in profitability, and in the marginal value of water across systems.

Baseline, Dry Year and 2020 Scenarios

Given a proper model specification, the baseline scenario should *resemble* current conditions within the basin, but not necessarily duplicate them. This is because we do not anticipate that water use in the basin is currently optimized. Figure 7 depicts area under cultivation, modeled and historical, by period beginning with Period 1 = Oct. 1:10 through Period 36 = September 21:30. Three crop types are depicted: paddy, polowijo crops and sugarcane. Polowijo crops are dry-footed, irrigated crops, including maize, soybean, and groundnut. We can see that the historical pattern is well approximated. We have observed that our model has a tendency to grow slightly less paddy in the first dry season (March–June) than has actually been grown, and somewhat more polowijo during the first and second dry seasons. We suspect that this is because paddy and maize (the dominant polowijo crop) are close economic competitors, and because we have allowed the cultivation of high-yielding hybrid maize, as consistent with

Figure 7. Area under cultivation, model and historical, 1995–2000.

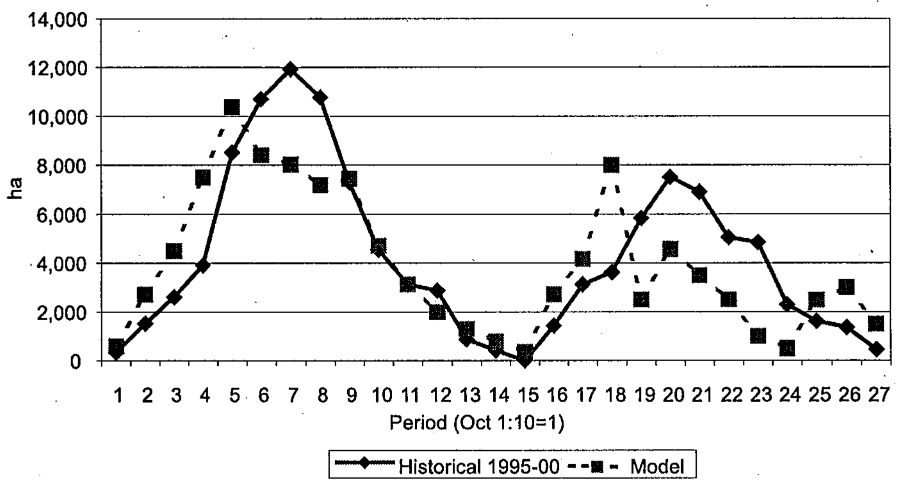


[12]The tertiary block is the most disaggregated unit for which irrigation delivery records are available.

our sample survey findings.[13] The model also grows slightly more sugar than is grown historically, possibly because we have specified sugar rendering rates of up to 8 percent during the irrigated sugarcane season (May–September) as compared to the 6.7 percent–7 percent rates more commonly observed throughout the year.[14]

Figures 8a (paddy) and 8b (polowijo) depict newly established crops, modeled and historical, by period. (Figure 7 differs from figure 8 in that the former depicts the standing crop during each time period, which embodies crop durations as well as dates of establishment, while the latter depicts only the hectares of newly established crop in each period). This is a more sensitive indicator of model performance. We observe that modeled paddy and polowijo planting schedules adhere closely to historical patterns, but with a tendency toward earlier planting, particularly of paddy, in both seasons. We believe that this may be because the model "knows" when the rain is coming, and how much, while in reality farmers do not, so they tend to be conservative in their planting decisions rather than risk losing a nursery crop to drought.

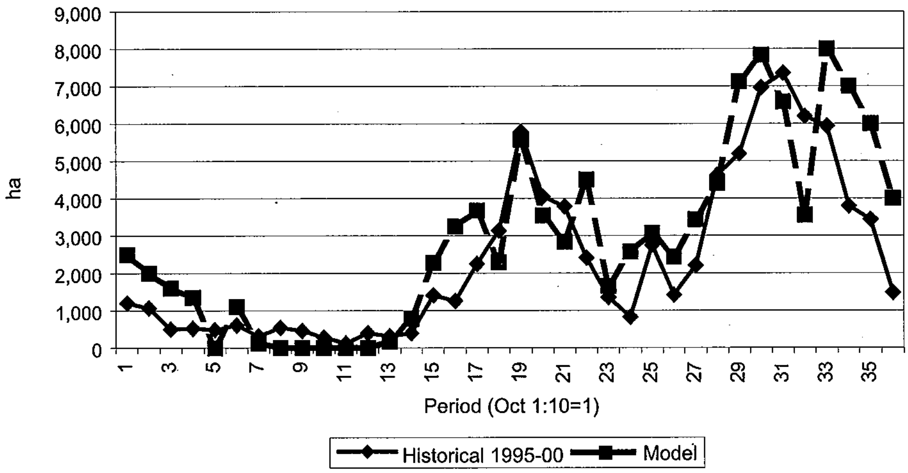
Figure 8a. New plantings, paddy, model and historical, 1995–2000.



[13]Hybrid maize produces higher yields, but has higher associated input costs, which are also represented within the model.

[14]In the model, sugarcane gross yields and sugar extraction rates are seasonally variable.

Figure 8b. New plantings, paddy, maize, model and historical, 1999–2000.



Figures 9a (baseline, 2020) and 9b (dry year) depict the basin inflows and outflows by period, for the Brantas main stem. The difference between these curves is the disappearance within the system, which consists of consumptive use and non-beneficial losses, such as reservoir and canal evaporation, and losses to unrecoverable groundwater. In each figure, a minimum flow constraint is indicated. This corresponds to a minimum flushing flow requirement in the Surabaya river. It is observed that during years of normal climatic conditions, roughly one-third of system inflows are depleted on an annual basis, and the majority of dry-season flows (June–November) depleted. The water-quality constraint is only occasionally binding, during August-October. In the dry year (Oct. 1996–Sept. 1997, measured inflows), depletion rates are higher at around 40 percent of annual flows, and the water quality (minimum flow) constraint is seen to be binding almost continuously during the dry season (May–September).

Figures 10a and 10b depict the stages of two of the three storage reservoirs within the Brantas, Sutami, and Selorejo, respectively.[15] In the model, Sutami storage is the combined storage of Sutami and Lahor reservoirs, which are connected by an ungated tunnel. Numerical simulation determined that, given the model timestep of 10 days, the two reservoirs could be modeled as a single unit except under extremely unusual (hypothetical) circumstances. The only constraints applied to reservoir operations were the seasonal requirements for flood pool in the wet season and minimum reserve storage in the dry season. In both cases, the model chooses solutions that involve more aggressive use of stored water. The relatively "flat" pattern in Sutami-Lahor arises due to the model's attempt to maximize hydropower production. Baseline and 2020 patterns differ very little, in spite of the shift in demand away from agriculture and toward municipal and industrial demand, which are less seasonal, over this period. Reservoirs are drawn down more aggressively during the dry year, particularly in the period July–September, as expected.

[15]No historical data exist for Wonorejo, which began operation in 2001.

Figure 9a. System inflows, outflows and flow constraint, baseline.

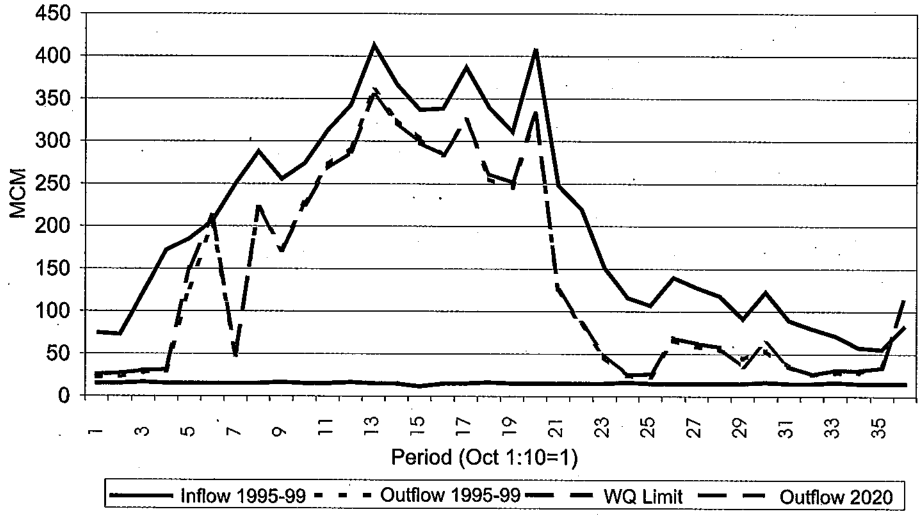


Figure 9b. System inflows, outflows and flow constraint, dry year (1996–1997).

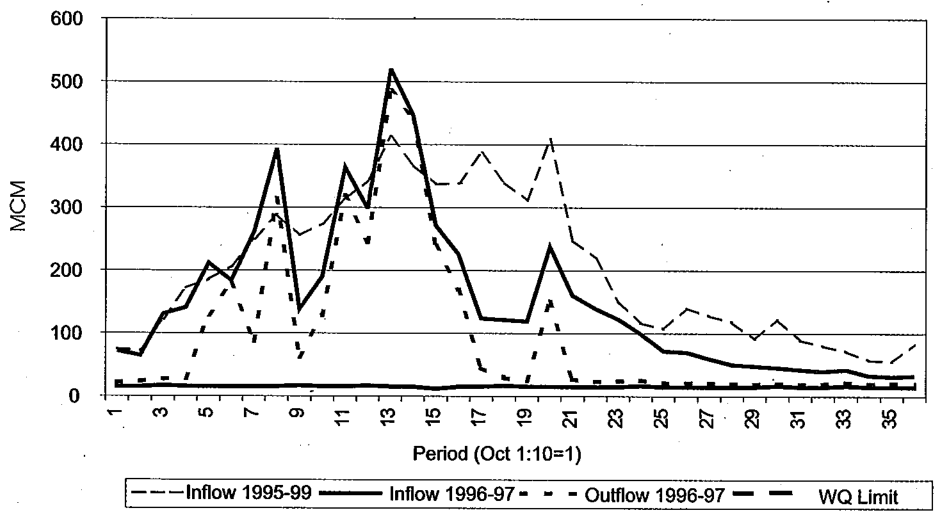


Figure 10a. Sutami-Lahor reservoir levels, modeled and historical.

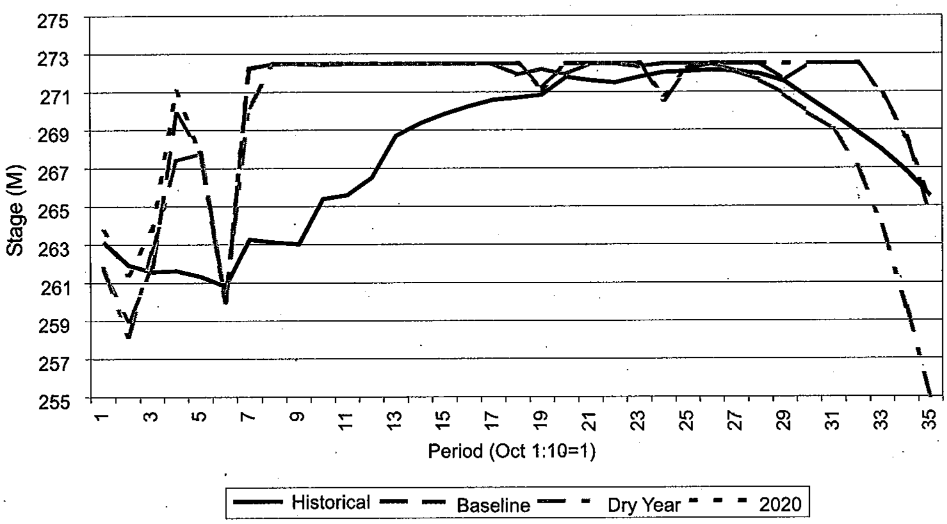
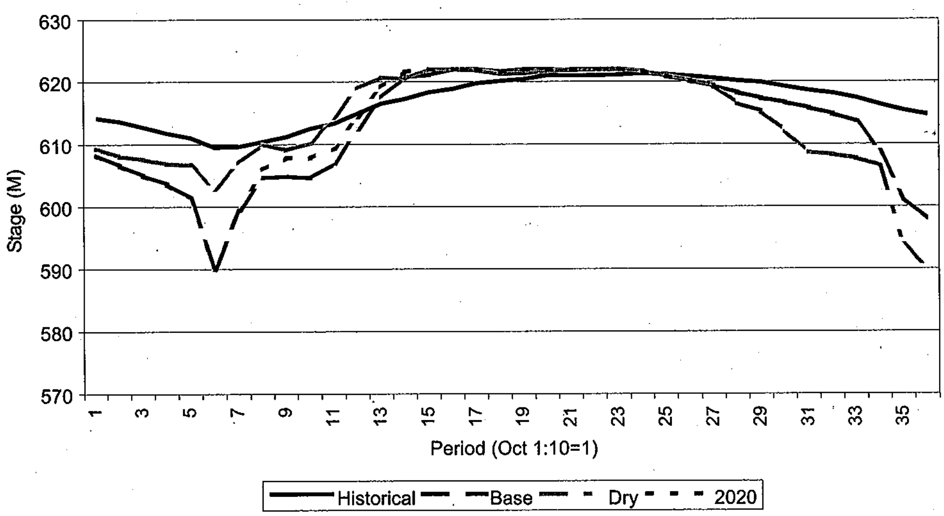


Figure 10b. Selorejo reservoir levels, modeled and historical.



Irrigated agricultural area and yield under each model scenario, and relative to historical levels, are summarized in table 4. A distinguishing feature of the scenarios is a reduction in the overall paddy planting, and a corresponding increase in the dry-footed irrigated (polowijo) crops. The model shows a preference for sugarcane relative to historical practice, although the model shifts sugarcane planting almost entirely to the irrigated season, May–August. Yields in general change very little, reflecting a tendency of the model to make adjustments in crop area and composition while maintaining full or near-full water supply.

In summary, the baseline and alternative scenarios provide evidence that the model is capable of recreating the overall dynamics of irrigated agriculture within the basin, and responds in a consistent manner to alterations in the boundary conditions. Model performance will almost certainly improve when all agricultural production functions have been respecified using forms that reflect the declining marginal value of water, as consistent with physical evidence.

Increasing Volumetric Water Charges

This set of scenarios was intended to evaluate the sensitivity of the model to changes in the level of a hypothetical volumetric water charge to irrigated agriculture. The analysis focuses on agriculture, and all parameters related to municipal, industrial and hydropower demand are constant throughout these scenarios, although these sectors are still competing with agriculture for available supplies. A primary objective was to discover how the model solutions embodied the various strategic responses described earlier—water saving, crop substitution, and shifting cropping calendars. In its present form, the model cannot simulate input substitution, as all inputs to crop production are parameters rather than decision variables in the current model specification.

The comparative model output appears in table 5. Figure 11 displays the change in cropping composition resulting from increasing water charges. Less paddy is planted, as anticipated, since paddy is a water-consumptive crop, requiring water for nursery, soil saturation, water-layer development, percolation, temperature and weed control, in addition to evapotranspirative demand. Planting shifts to polowijo crops, primarily maize, and sugarcane to a lesser extent. The extent of the area reallocation is small, however—on the order of 1–2 percent. Shifts in production mirror those of planted area, reflecting negligible changes in yield. The timing of planting shows very little response to increased charges as well. Figure 12 displays the planting schedule associated with each level of water charge for paddy. Only minor adjustments occur, and these are primarily within-season as distinct from across-season.

The primary adjustments relative to historical cropping patterns were already evident in the baseline scenario, in which farmers planted paddy earlier in both seasons, and reallocated land from paddy to polowijo during the dry season. The reasons that further changes of a non-marginal nature did not accompany increasing water charges again relate to marginal conditions—even water charges of 35 Rp/m^3 lie below the marginal value of water for each of these crops at full use, at least according to the current specifications of production functions.

The strategy of accommodation to increasing water charges is only one output of interest, however. We are also interested in the net impact of such charges on the farm economy. Table 6 summarizes the structure of costs and revenues by crop and by water charge. Table 7 summarizes the per-hectare costs for each crop and price scenario, and water's corresponding

Table 4. Summary of model output, irrigated agriculture.

	Historical	Baseline	% Change	Dry year	% Change	2020	% Change
Planted area (in ha)							
Paddy							
Wet season	69,452	69,061	-0.6	68,681	-1.1	57,060	-17.8
Dry season 1	44,036	36,447	-20.8	31,831	-27.7	30,065	-31.7
Total	113,487	105,508	-7.6	100,512	-11.4	87,125	-23.2
Polowijo							
Wet season	8,593	11,906	27.8	11,894	38.4	10,945	27.4
Dry season 1	31,218	38,828	19.6	39,000	24.9	32,617	4.5
Dry season 2	44,973	54,503	17.5	51,827	15.2	42,529	-5.4
Total	84,785	105,237	19.4	102,721	21.2	86,092	1.5
Sugarcane	19,499	24,250	19.6	24,694	26.6	24,075	23.5
Total planting	217,771	234,995	7.3	227,927	4.7	197,292	-9.4
Cropping intensity	2.29	2.47	-	2.40	-	2.40	-
Yields (in mt/h)							
Paddy	5.48	5.63	2.7	5.53	1.0	5.74	4.7
Maize	3.42	5.37	36.3	5.36	56.6	5.45	59.4
Soybean	1.21	1.36	11.1	1.25	3.2	1.45	20.0
Groundnut	1.09	1.13	3.4	1.12	3.2	1.20	10.2
Sugarcane	na	6.11	-	6.08	-	6.12	-

Note: Historical values are based on crop years 1995/96–1999/00; Percent changes relative to historical; mt/ha = metric tons per hectare; na = data not available. Percent changes relative to historical.

Table 5. Planted area, production and yield impacts of water charge.

	Rp 00	Rp 05	Rp 10	Rp 15	Rp 20	Rp 25	Rp 30	Rp 35
Planted area (ha)								
Paddy	105,508	105,272	104,828	104,522	103,996	103,711	103,540	103,265
WS paddy	69,061	68,936	68,786	68,624	68,394	68,300	68,161	67,984
DS1 paddy	36,447	36,336	36,042	35,898	35,602	35,410	35,379	35,281
Polowijo	105,237	105,339	105,654	105,628	105,881	105,975	106,055	106,097
Maize	88,497	88,545	88,671	88,572	88,731	88,724	88,860	88,989
Soybean	11,083	11,095	11,207	11,240	11,320	11,435	11,443	11,402
Groundnut	5,657	5,699	5,776	5,815	5,830	5,815	5,751	5,706
Sugarcane	24,250	24,313	24,400	24,541	24,690	24,784	24,851	24,956
Production (mt)								
Paddy	594,089	592,820	590,379	588,605	585,625	584,100	583,056	581,474
WS paddy	397,246	396,515	395,636	394,681	393,372	392,835	392,050	391,051
DS1 paddy	196,842	196,305	194,743	193,924	192,253	191,265	191,006	190,423
Polowijo	496,418	496,831	497,633	497,199	498,192	498,442	499,136	499,745
Maize	474,953	475,308	475,882	475,362	476,229	476,340	477,097	477,840
Soybean	15,080	15,094	15,227	15,256	15,359	15,514	15,515	15,425
Groundnut	6,385	6,428	6,524	6,582	6,604	6,588	6,524	6,479
Sugarcane	148,135	148,445	148,870	149,565	150,293	150,754	151,085	151,599
Yield (mt/ha)								
Paddy	5.631	5.631	5.632	5.631	5.631	5.632	5.631	5.631
WS paddy	5.752	5.752	5.752	5.751	5.752	5.752	5.752	5.752
DS1 paddy	5.401	5.403	5.403	5.402	5.400	5.401	5.399	5.397
Polowijo	4.717	4.716	4.710	4.707	4.705	4.703	4.706	4.710
Maize	5.367	5.368	5.367	5.367	5.367	5.369	5.369	5.370
Soybean	1.361	1.360	1.359	1.357	1.357	1.357	1.356	1.353
Groundnut	1.129	1.128	1.130	1.132	1.133	1.133	1.134	1.135
Sugarcane	6.109	6.106	6.101	6.094	6.087	6.083	6.080	6.075

Note: mt = metric tons; ha = hectare.

Figure 11. Changes in area by crop in response to increasing water charges.

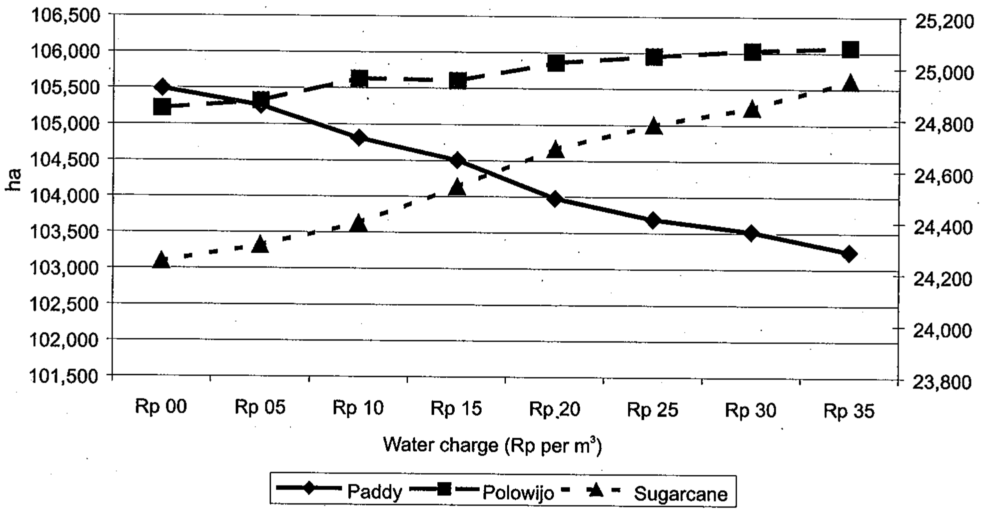


Figure 12. Changes in planting date in response to increasing water charges.

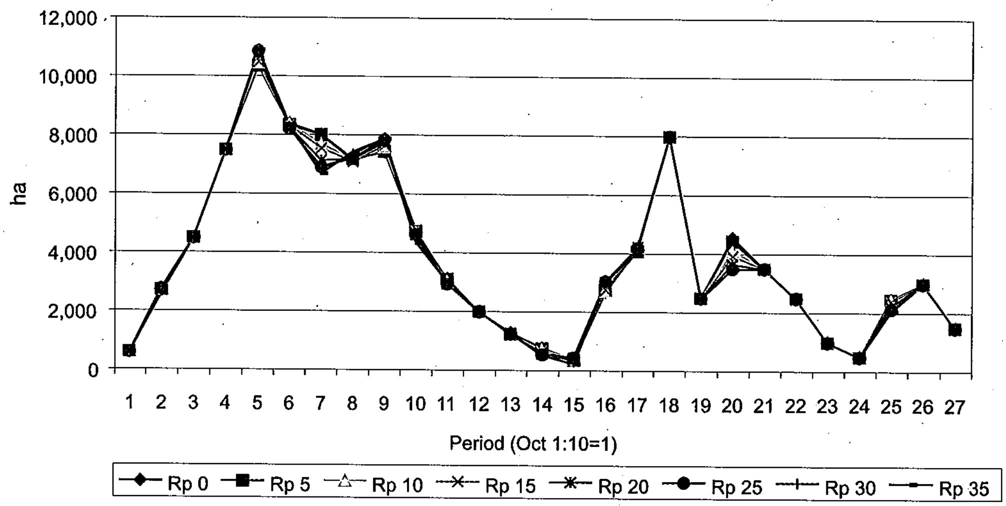


Table 6. Structure of costs and revenues, water charge.

	Rp 00	Rp 05	Rp 10	Rp 15	Rp 20	Rp 25	Rp 30	Rp 35
Gross revenue in Rp million								
Paddy	592,994	591,730	589,307	587,497	584,498	582,925	581,847	580,250
WS paddy	396,448	395,723	394,846	393,869	392,529	391,952	391,146	390,135
DS1 paddy	196,547	196,007	194,461	193,628	191,969	190,973	190,701	190,115
Polowijo	442,540	442,906	443,990	443,782	444,724	444,905	445,292	445,548
Maize	396,278	396,481	397,028	396,584	397,273	397,240	397,830	398,380
Soybean	25,829	25,856	26,085	26,136	26,317	26,585	26,586	26,435
Groundnut	20,432	20,570	20,877	21,062	21,134	21,080	20,877	20,733
Sugarcane	546,615	547,760	549,327	551,892	554,579	556,278	557,501	559,396
Costs of cultivation (excluding water) in Rp million								
Paddy	296,119	295,457	294,198	293,375	291,909	291,153	290,688	289,918
WS paddy	193,937	193,578	193,143	192,707	192,081	191,846	191,473	190,989
DS1 paddy	102,182	101,879	101,055	100,668	99,828	99,306	99,215	98,928
Polowijo	207,328	207,544	208,095	207,924	208,444	208,506	208,796	209,021
Maize	184,774	184,916	185,266	185,011	185,456	185,437	185,817	186,185
Soybean	13,027	13,037	13,123	13,147	13,200	13,303	13,309	13,234
Groundnut	9,527	9,591	9,706	9,766	9,788	9,766	9,670	9,602
Sugarcane	266,750	267,446	268,398	269,956	271,589	272,621	273,364	274,515

Continued

Table 6. Continued.

	Rp 00	Rp 05	Rp 10	Rp 15	Rp 20	Rp 25	Rp 30	Rp 35
Water charges (Rp million)								
Paddy	0	3,869	7,700	11,511	15,244	18,991	22,726	26,410
WS paddy	0	1,896	3,784	5,663	7,526	9,396	11,233	13,046
DS1 paddy	0	1,974	3,916	5,848	7,718	9,595	11,492	13,364
Polowijo	0	1,701	3,411	5,115	6,833	8,550	10,269	11,994
Maize	0	1,395	2,790	4,179	5,574	6,964	8,374	9,788
Soybean	0	214	432	649	871	1,102	1,322	1,544
Groundnut	0	92	189	288	388	484	573	662
Sugarcane	0	1,243	2,495	3,762	5,043	6,324	7,606	8,909
Net crop value (Rp million)								
Paddy	296,876	292,403	287,409	282,611	277,345	272,781	268,433	263,922
WS paddy	202,511	200,249	197,918	195,498	192,922	190,709	188,439	186,100
DS1 paddy	94,365	92,154	89,491	87,112	84,423	82,072	79,994	77,822
Polowijo	235,212	233,661	232,484	230,743	229,447	227,849	226,227	224,533
Maize	211,504	210,169	208,973	207,394	206,243	204,839	203,639	202,407
Soybean	12,803	12,605	12,530	12,341	12,245	12,180	11,955	11,657
Groundnut	10,905	10,887	10,981	11,009	10,958	10,830	10,633	10,469
Sugarcane	279,865	279,071	278,435	278,174	277,947	277,333	276,530	275,971

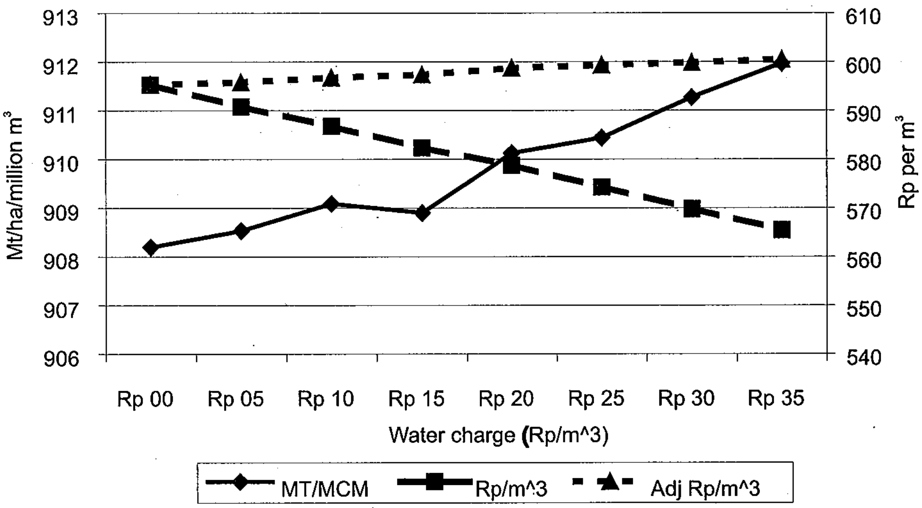
Table 7. Water as a cost of production.

	Rp 00	Rp 05	Rp 10	Rp 15	Rp 20	Rp 25	Rp 30	Rp 35
Water costs in (Rp/ha)								
Paddy	0	36,756	73,454	110,129	146,583	183,114	219,488	255,752
WS paddy	0	27,501	55,018	82,522	110,035	137,573	164,807	191,896
DS1 paddy	0	54,314	108,639	162,903	216,794	270,954	324,836	378,799
Polowijo	0	16,150	32,285	48,428	64,532	80,682	96,823	113,051
Maize	0	15,756	31,463	47,181	62,814	78,495	94,236	109,989
Soybean	0	19,263	38,535	57,702	76,958	96,351	115,497	135,455
Groundnut	0	16,207	32,787	49,487	66,555	83,231	99,648	116,032
Sugarcane	0	51,131	102,242	153,283	204,249	255,180	306,076	356,997
Water costs as % of total costs of cultivation								
Paddy	0.0	1.3	2.6	3.8	5.0%	6.1%	7.3%	8.3%
WS paddy	0.0	1.0	1.9	2.9	3.8%	4.7%	5.5%	6.4%
DS1 paddy	0.0	1.9	3.7	5.5	7.2%	8.8%	10.4%	11.9%
Polowijo	0.0	0.8	1.6	2.4	3.2%	3.9%	4.7%	5.4%
Maize	0.0	0.7	1.5	2.2	2.9%	3.6%	4.3%	5.0%
Soybean	0.0	1.6	3.2	4.7	6.2%	7.6%	9.0%	10.5%
Groundnut	0.0	1.0	1.9	2.9	3.8%	4.7%	5.6%	6.5%
Sugarcane	0.0	0.5	0.9	1.4	1.8%	2.3%	2.7%	3.1%

fraction of input costs. These numbers embody the attempts farmers make to minimize the burden of increasing water charges, however limited in this case.

We are finally interested in water use efficiency. Figure 13 depicts the physical output in metric tons per hectare per million cubic meters delivered to the field, which is the basis of the hypothetical water charge in this model, as a function of water charge. This is seen to increase, as a consequence of improved physical efficiency induced by the water charge. Figure 13 also depicts the net returns in rupiah per cubic meter, also aggregated over all crops. This is seen to decline, reflecting the water charge as an increasing cost of production. However, when water charges are added to net income, reflecting the fact that these fees are essentially transfers of wealth from one party (farmer) to another (some institution), we see a modest increase in the implicit value of water in irrigated agriculture induced by the increasing cost of the resource.

Figure 13. Water-use efficiency and net returns as affected by water price.



Conclusion: Policy Modeling Scenarios

The development of the integrated model of the Brantas basin is not an end in itself, but rather provides a tool by which to accomplish the broader objectives of the project. The value of the policy-simulation model output will be highest when it is used to explore scenarios for which a conventional, pro forma benefit-cost analysis is either unfeasible or likely to yield biased results through failure to anticipate the situation dynamics correctly. The benefits of scenario-driven policy simulation are not limited to the public agencies responsible for planning and implementing basin-scale water-resources strategies. Policy modeling offers, in addition, a means by which each community of stakeholders can anticipate how their interests are likely to be affected by proposed policies, and an opportunity for these communities to participate in strategic water-resources planning, through the participatory development of these scenarios.

There are four items on our current policy-simulation agenda. They are a) an evaluation of the relationship between water-charge and cost-recovery policy and the economic health of the irrigated agriculture sector, b) an analysis of the impact of varying levels of expenditures on the operation and maintenance (O&M) of hydraulic infrastructure, c) a cost-benefit analysis of the construction of two proposed new dams in the Brantas, and d) an evaluation of proposed institutional reforms, including the establishment of property rights in water and the creation of water markets. These items are seen to be extensively interrelated. A brief justification for each follows.

The first analysis, an evaluation of the relationship between water-pricing policy and the economic health of the irrigated agriculture sector, is a primary objective of IFPRI/ADB RETA 5866. The technical assistance is predicated on the observations that within many regions of East and South Asia, and in the Brantas, demand is increasing for both agricultural commodities and freshwater resources, competition is increasing between the agriculture and nonagriculture sectors for available freshwater, the performance of irrigation infrastructure is in decline, new irrigated area is increasingly expensive to develop, and foreign direct assistance will not continue at historical levels. All of these developments represent implicit or explicit threats to the economic well-being of the agricultural community. While it is clear to many that the long-term interests of the agricultural community are not well served by the ongoing, heavy subsidy of water, it is equally clear that farmers cannot outbid new industrial and municipal users (and possible others) for increasingly scarce supplies. We can use policy simulation to explore a range of water-charge structures and cost-recovery mechanisms, in terms of overall efficiency and with particular emphasis on the well-being of the irrigation sector.

The second objective, an analysis of the impact of varying levels of expenditures on the O&M of hydraulic infrastructure is, in many respects, a specific component of the first. The link between the progressive underfunding of irrigation system O&M and the subsequent deterioration of system performance relative to design standards have been recognized for over a decade (see, e.g., Easter 1999). Nevertheless, we still have too little internally consistent data on the two processes to perform a conventional benefit-cost analysis, which would allow the design of financing arrangements that are optimal jointly to farmers and public agencies, and which reflect a long-term commitment to financial self-sufficiency in the irrigation sector. Pioneering simulation work on evaluating system maintenance versus early rehabilitation strategies has been done by Skutsch (1998, 1999), but this study has greatly simplified the relationship between maintenance investment, system efficiency and overall system productivity. We intend to perform an analysis at the river-basin level, in which the relationship between levels of investment and efficiency over time can be made explicit. This approach will allow farmers to respond to varying levels of irrigation-service quality, and will help them to determine which level of maintenance is optimal, and how it can be financed.

The model's ability to simulate the addition of new infrastructure within the basin hydrosystem will permit us to perform an ex ante analysis of the benefits associated with constructing two new dams and power plants within the Brantas. JICA (1998) has identified two proposed projects, Beng and Kedung Warak, as potentially cost-effective. These multipurpose structures would contribute an additional 150-200 MCM of usable storage to the basin. They are pump-and-store systems, however, and the anticipated economic viability of these projects is highly sensitive to estimates of growth in demand and willingness to pay for water, primarily by domestic and industrial users. We will simulate the economic performance of these proposed structures under a range of scenarios concerning both demand and climatic input.

Finally, we can use policy simulation to investigate the feasibility of several institutional reforms proposed under the World Bank-supported WATSAL (Water Resources Sector Adjustment Loan) process, initiated in 1999 (World Bank 1999) to support water-sector reforms in Indonesia. The proposed reforms associated with WATSAL are sweeping, but two in particular would benefit strongly from ex ante policy simulation and analysis. Under objective b), "Strengthening of the institutional and regulatory framework for integrated and equitable river basin management," a specific adjustment outcome is "Establishing a national framework for an enforceable water use rights system for surface and groundwater allocation, and a uniform framework of water abstraction licensing by provincial governments." Under objective d), "Improving the performance and sustainability of irrigation systems," outcomes include "Adopting a national framework for the establishment by district governments of autonomous and self-financing water user associations (WUAs) and water user association federations (WUAFs) to manage irrigation networks" and "Implementing a nation-wide Irrigation Service Fee framework for sustainable financing of operation, maintenance and asset amortization of irrigation schemes by the local government, WUAs and WUAFs" (1999, ii). During this period of water-sector reform, the value of information is extremely high, and policy simulation can be a tool of great value.

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Alternative Futures for Water Allocation and Use in the Dong Nai River Basin, Vietnam

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Introduction

Recent reforms in Vietnam's water sector, in combination with increasing scarcity and vulnerability of existing water resources, and declining public funding available for large-scale infrastructural investment in the sector, have led to an increased awareness for the need to analyze water-resources allocation and use in an integrated fashion, at the basin scale and from an economic-efficiency perspective.

In the time frame of only slightly more than one year, Vietnam initiated a series of major reforms in the country's water sector—including the enactment of the Vietnamese Water Resources Law in 1999, the subsequent Decision on the Establishment of a National Water Resources Council in June, 2000, and the issuance of decisions regarding the establishment of Planning Management Councils for the Red river delta, the Mekong delta, and the Dong Nai river basins (DNRB) in April, 2001. The Water Resources Law has led to a series of additional initiatives in the water sector, including the drafting of legislation regarding the licensing of groundwater and, eventually of surface water. Finally, since 1998, the Ministry of Agriculture and Rural Development (MARD) has been attempting to raise the level of irrigation service fees (ISF) collected in the country to better cover irrigation operation and maintenance (O&M) costs.

At the same time, scarcity of water resources is becoming a more common phenomenon in the country, albeit still lower in priority than the serious annual flooding problems, particularly in the Mekong delta. During the drought of early 2002, various regions in southern Vietnam saw their harvests threatened, faced depleted groundwater supplies for drinking water and land subsidence, and even experienced forest fires.

Vietnam's water resources are also becoming more and more vulnerable to increased pollution levels that have accompanied the rapid industrial and economic growth over the last decade. The Dong Nai river basin (DNRB), where slightly more than half of industrial gross domestic product (GDP) in the country is produced, is already facing high pollution levels, without adequate treatment facilities.

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[1]This paper is a product of the Asian Development Bank Region Technical Assistance ADB No. 5866 "Irrigation Investment, Fiscal Policy, and Water Resource Allocation in Indonesia and Vietnam." It combines work by the International Food Policy Research Institute (IFPRI), Washington, D.C., the Sub-Institute for Water Resources Planning (SIWRP), Ho Chi Minh City, Vietnam, and the Sub-National Institute for Agricultural Planning and Projections (Sub-NIAPP), Ho Chi Minh City, Vietnam. This paper expands upon an earlier paper titled "Water Allocation and Use in the Dong Nai River Basin in the Context of Water Institution Strengthening," prepared for the workshop "Integrated Water Resources Management in a River Basin Context" held in Malang, Indonesia, January 15-19, 2001.

Public funding for large-scale water infrastructural investment projects has been declining across the Asia-Pacific region, particularly for large-scale reservoirs and irrigation schemes. The Government of Vietnam has started to move from a supply-driven approach to investment in the sector to a more demand-based approach, including river-basin planning, a wider range of investment approaches, including build-operate-transfer (BOT) for both bulk water supply and hydropower projects as well as small private water suppliers in urban areas, and a more participatory process. But more needs to be done to accommodate increasing water demands with limited financial resources.

To make appropriate water allocation and investment decisions, an integrated approach to the resource has to be taken. This paper presents the development, application and preliminary results from an integrated economic-hydrologic river-basin model for the DNRB in southern Vietnam that attempts to incorporate these issues into one comprehensive modeling framework, as a tool to assist in decision making.

The following sections provide a brief overview of the DNRB, and then introduce the modeling framework and structure, and describe the data utilized. The second part of this paper presents a summary of baseline results, sensitivity analyses and alternative scenarios. The paper ends with some concluding remarks.

Background on the Dong Nai River Basin (DNRB)

The DNRB is the largest national river basin in Vietnam and the economic center of the country with a catchment area of 40,683 square kilometers. The basin is located in the southern part of the country and includes lowland areas that are subjected to annual flooding in the wet season and salinity intrusion in the dry season as well as mountainous highland areas rising up to 1,600 m above sea level. In addition, for administrative and analysis purposes, a series of several smaller basins on the coast[2] are combined with the main Dong Nai basin, adding to a total surface area of 48,471 km^2 within Vietnam, or about 15 percent of Vietnam's land surface area (see also figure 1).

The basin includes ten provinces and the Ho Chi Minh City (HCMC).[3] Some characteristics of these provinces are shown in table 1. As can be seen, the DNRB is highly developed, with a relatively low share of agricultural GDP, relatively high income per capita, and a high population density, compared with other regions in Vietnam. It accounts for slightly more than half of the total industrial GDP in Vietnam. Industrial production is concentrated in the HCMC—Bien Hoa-Ba Ria Vung Tau economic zone. More recently, Binh Duong province has emerged as an industrial center, with an industrial growth of 26 percent per year during 1996–1999, albeit from low levels. Moreover, whereas the total population in Vietnam increased at 1.6 percent per year from 1995 to 2000, the basin population increased at an annual rate of 2.6 percent per year during the same period, to reach approximately 14 million in 2000. Although

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[2]In the following, references to the Dong Nai basin include the surrounding coastal area, unless specified otherwise.

[3]About 19.4 percent of Dak Lak, 90 percent of Lam Dong, and 51.3 percent of Long An are included in the basin area. Unless mentioned otherwise, only basin areas of these provinces are referred to.

Figure 1. The Dong Nai river basin.

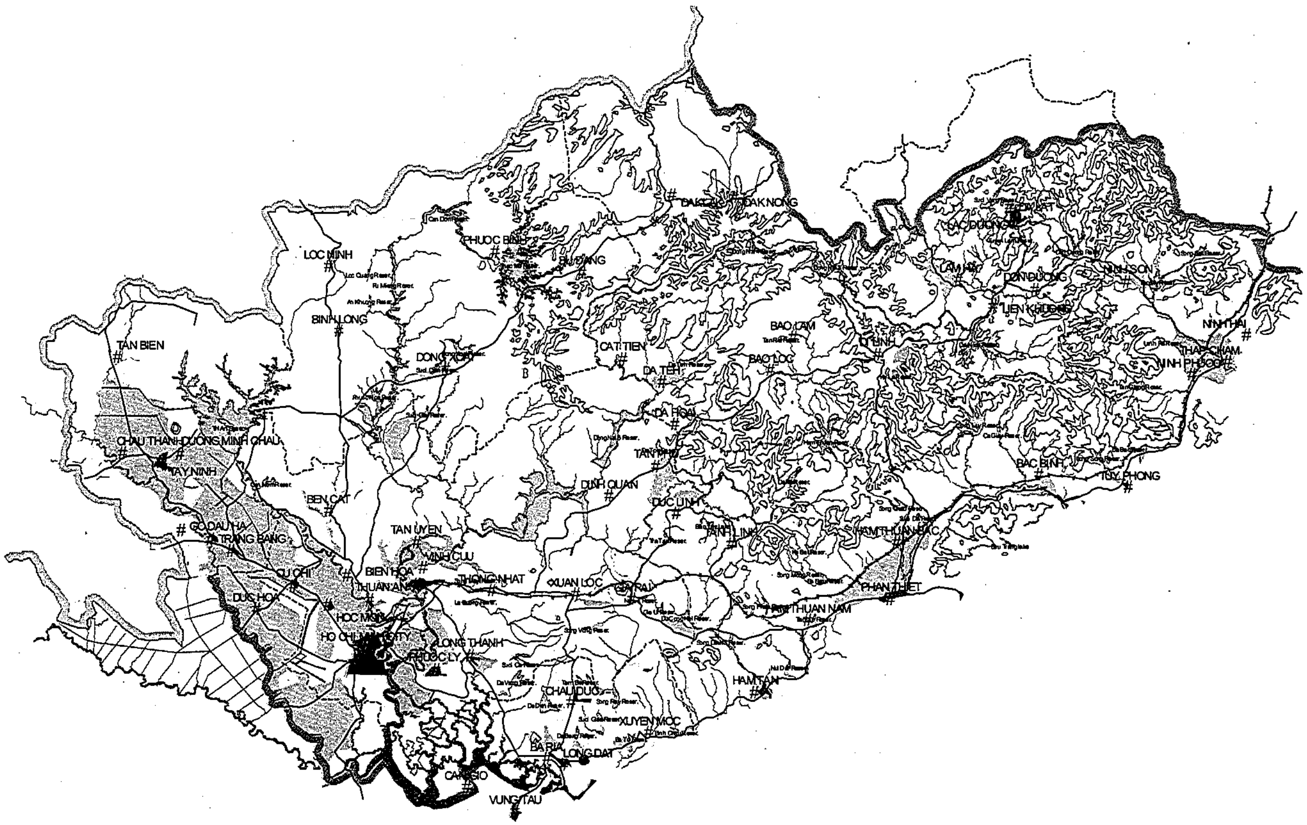


Table 1. Economic indicators for the provinces in the Dong Nai river basin.

	Land area 2000 (ha)	Gross irrigated area 1999 (ha)	Population 2000 ('000)	GDP 1999 (M US$)	Share agriculture GDP 1999 (%)	Share industrial GDP 1999 (%)	Income per capita 1999 (US$/cap)
Binh Duong	269,555	20,693	738	376	19	55	29.1
Binh Phuoc	685,598	24,844	687	114	65	8	23.6
Binh Thuan	783,809	71,231	1,066	141	47	21	19.9
Ba Ria - Vung Tau	190,000	20,762	823	3,137	5	82	32.2
Dak Lak	388,909	12,097	99	433	71	8	27.7
Dong Nai	589,474	59,188	2,039	878	24	50	31.9
HCMC	209,505	69,742	5,222	5,036	2	44	59.3
Long An	188,153	143,147	810	414	53	19	23.2
Lam Dong	976,440	88,245	1,038	222	60	14	29.1
Ninh Thuan	336,006	42,307	516	103	53	13	16.6
Tay Ninh	402,812	199,619	979	268	45	19	22.2
Total	5,020,261	751,874	14,018	11,123	14	51	

Note: GDP and income refer to the entire province, not just basin area.
Source: Land area: Sub-NIAPP; Gross irrigated area: adjusted from SIWRP 1993; Population and GDP: various statistical yearbooks; Income per capita: GSO 2001.

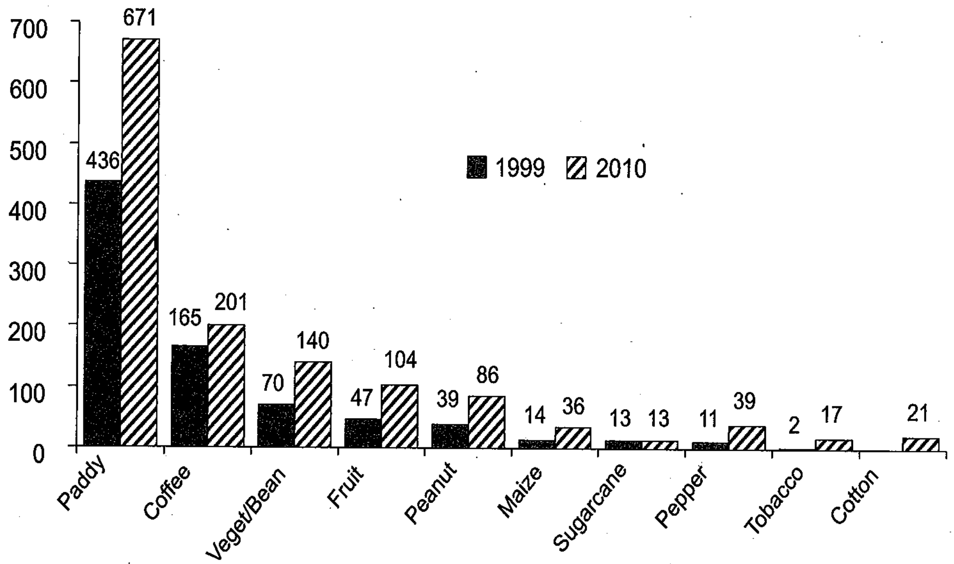
the share of agricultural GDP has been declining over time, the agriculture sector in the basin is highly diversified and dynamic, with products ranging from basic staples like rice and maize to raw materials for the local industry, including cotton, rubber, and sugarcane, to high-value crops, like coffee, fruit, grapes, pepper, tea, and vegetables. Figure 2 shows the areas of major irrigated crops for 1999 and projected for 2010. Finally, although the basin can be considered relatively rich on average, it includes some of the poorest districts and provinces in the country, in particular, Ninh Thuan and Binh Phuoc provinces as well as several rural districts in Binh Thuan, Dak Lak, and Lam Dong provinces.

The total runoff in the basin is estimated at about 47 billion cubic meters (BCM), including about 6-7 BCM of Mekong flows. Rainfall averages 2,000 mm, but can be as low as 700 mm in some coastal areas. The DNRB has five major rivers: the Dong Nai mainstream, the Be, the Sai Gon, and the La Nga as major tributaries, and the Vam Co Dong system that joins the Dong Nai just before the outlet into the sea. In addition to the flows from the Mekong river, the Dong Nai river transfers about 20 m^3/sec (equal to 643 million m^3) to the Cai river basin in Ninh Thuan province in the coastal region.

The basin ranks second in hydropower potential in the country. In 2000, the total installed hydropower capacity reached 1,182 megawatts with an average annual power production of 4,881 gigawatt hours. The total investment cost of existing hydropower projects is estimated at 1,105 million US dollars (Tri An, Thac Mo, and Ham Thuan Da Mi reservoirs). Selected hydropower parameters are shown in table 2. In addition, the basin includes Dau Tieng, the largest irrigation reservoir in the country. Dau Tieng was built in 1985 with World Bank-support. Although the reservoir never reached its initially designed command area of 172,000 hectares (Feasibility project no. 190 TTg dated 18/5/1979) and the later reduced area of 133,530 hectares (Decision No. 498-TTg, dated 12/10/1993), its functions have been enlarged to include indirect irrigation water deliveries for the Vam Co Dong system through canal and irrigation return flows, water supply for HCMC and other major urban centers, deliveries to major industries in Tay Ninh province, and salinity control.

On the institutional side, several reforms in the water sector have recently impacted upon or will impact on the basin in the near future. In April, 2001, MARD established a basin Planning Management Council for the DNRB (Decision No. 38/2001/QD/BNN-TCCB, dated 09.04.2001). The members of the council include several ministries involved in water-resources allocation. The Council will be chaired by the Vice Minister of MARD. Operating rules for the organization are still being worked out. However, it is anticipated that, at least at the outset, the Council will be limited to water-resources planning. ADB will support the implementation of the Council for the DNRB in an upcoming project. Moreover, since 1999, the Department of Science, Technology, and Environment of HCMC has developed plans to establish a river-basin committee focused on environmental protection in the DNRB. This process culminated recently in the proposal to the Government of Vietnam to establish a "Management Committee for the Sai Gon—Dong Nai Rivers' Basin Environmental Protection Programme" (Vietnam News, May 4, 2002). Additional information on the actors and agencies involved in water management in the DNRB can be found in Svendsen et al. 2002.

Figure 2. Irrigated harvested areas, Dong Nai river basin, 1999 and projected 2010.



Sources: 1999 data—for rice and perennial crops, Sub-NIAPP; for other crops, authors; 2010 data—Sub-NIAPP.

The combination of rapid increases on the pressure on water resources and recent reforms in water management and allocation make the basin a useful case study for competitive water uses that might occur in other basins in Vietnam or elsewhere in Asia in the future.

Modeling Framework

The model developed for the DNRB draws on previous economic-hydrologic modeling carried out at IFPRI, in particular for the Maipo river basin in Chile (Rosegrant et al. 2000). The model belongs to the class of integrated economic-hydrologic river-basin models and includes hydrologic, economic and institutional components. The model focus is on the economic component.

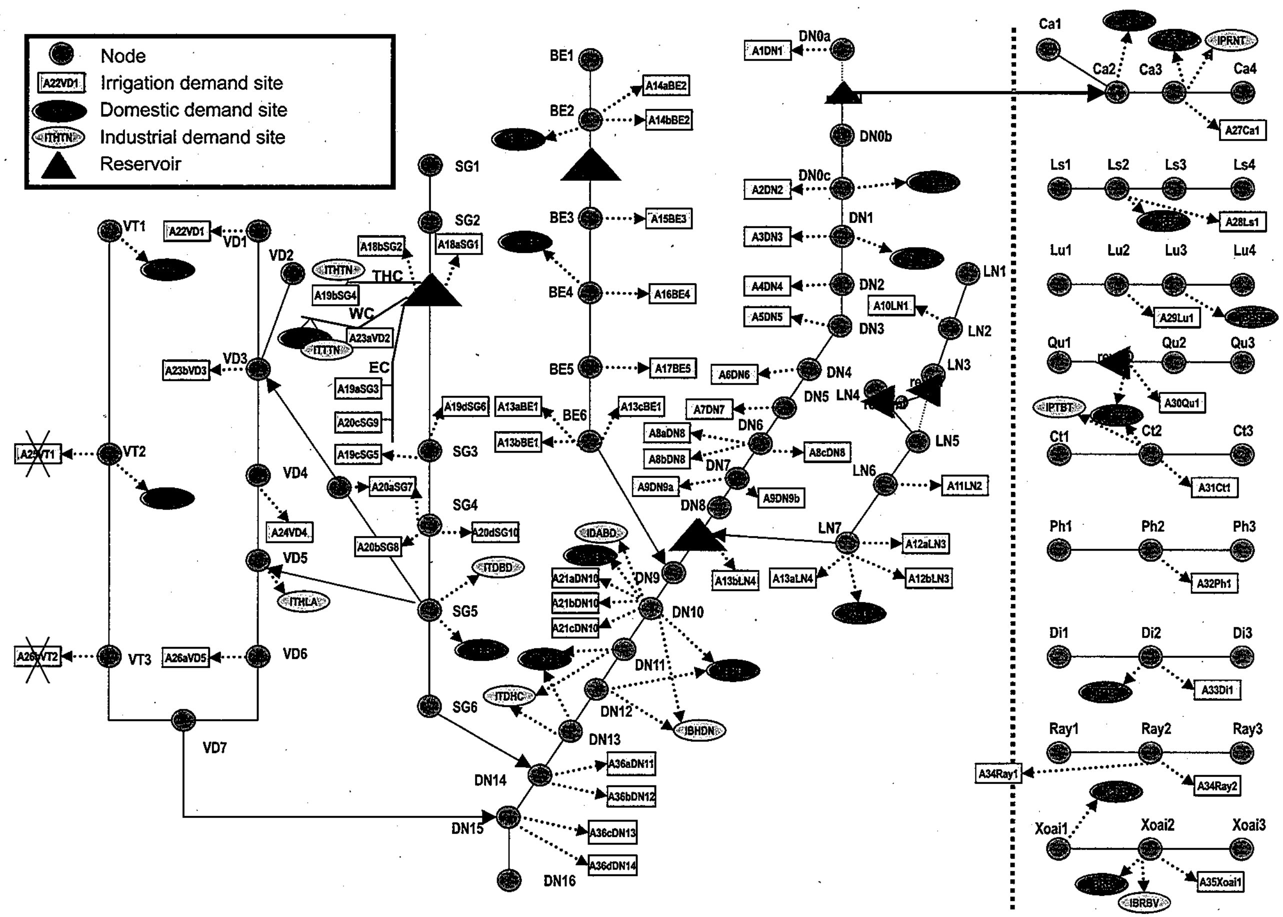
The river-basin model is developed as a node-link network, which is an abstracted representation of the spatial relationships between the physical entities in the river basin. Nodes represent river reaches, reservoirs and demand sites, and links represent the linkage between these entities (figure 3). Inflows to these nodes include water flows from the headwaters of the river basin, as well as local rainfall drainage. Flow balances are calculated for each node at each time period, and flow transport is calculated based on the spatial linkages in the river-basin network.

Table 2. Existing and planned hydropower projects in the Dong Nai basin.

Name	Catchment (km^2)	Year	Uses	Capacity (MW)	Annual output (GWh)	Active storage (million m^3)	Net head (m)
Dong Nai river							
Tri An	14,800	1989	HP/FC	400	1,700	2,542	50
Dai Ninh	1,158		HP/IR/WS	300	1043	252	550
Dong Nai 1	2,804		HP	45	188	240	60
Dong Nai 2	3,141		HP	80	346	239	82
Dong Nai 3	3,612		HP	240	794	1,248	120
Dong Nai 4	3,782		HP	270	906	37	140
Dong Nai 5	54,62		HP	173	823	39	67
Dong Nai 6	6,272		HP	180	774	393	54
Dong Nai 8	9,050		HP	195	719	923	48
Be river							
Thac Mo	2,200	1995	HP	150	610	1,260	
Can Don (BOT)	3,440	Const.	HP	72	295	80	30
Fu Mieng	4,110		HP	54	242	62	43
Phuoc Hoa	5,420		IR				
Smaller Dong Nai tributaries							
Da Nhim	775	1963	HP	160	1,025	156	800
Da M'Bri	234		HP	66	295	60	350
Dak R'Tih	718		HP	105	472	175	320
Da Siat	115		HP	16	80	304	255
Song Luy	554		IR			132	
La Nga river							
Ham Thuan	1,280	2000	HP	300	957	523	250
Da Mi	83	2000	HP	172	595	17	142
La Nga 3 (Ta Pao)			IR	62			
Sai Gon river							
Dau Tieng	2,700	1985	IR/WS			1,110	
Total (pl + ex)				3,040	11,864	9,792	

Notes: FC = Flood control; HP = Hydropower; IR = Irrigation; WS = Water supply.

Figure 3. Dong Nai river-basin network.



For modeling purposes, provinces are considered the major modeling units in the river-basin model. Agricultural demand sites are delineated according to 37 sub-catchments and administrative boundaries, resulting in 60 irrigation demand sites.[4] For domestic demand sites, adjacent districts have been summed up, yielding 48 domestic demand sites. For industrial water use, 12 demand sites are delineated for the provinces with major industrial water use: Ba Ria-Vung Tau, Binh Duong, HCMC, Dong Nai, as well as several provinces with less industrial development: Binh Thuan, Long An, Ninh Thuan and Tay Ninh. The model also incorporates the major existing reservoirs for hydropower production, irrigation and flood control.

The model thus incorporates both off-stream and in-stream water uses. Off-stream uses include water diversion for irrigated agriculture, domestic uses and industrial water uses. In-stream uses include flows for hydropower generation and minimum in-stream flows to control saltwater intrusion.

Thematically, the modeling framework includes three components: a) hydrologic components, including the water balance in reservoirs, river reaches and crop fields; b) economic components, including the calculation of benefits from water uses by sector, demand site and country; and c) institutional rules and economic incentives that impact upon the hydrologic and economic components (figure 4). Water supply is determined through the hydrologic water balance in the river system while water demand is determined endogenously within the model, based on functional relationships between water and productive uses in irrigated agriculture, domestic-industrial areas, wetlands, fisheries, and hydropower. Water supply and demand are balanced, based on the objective of maximizing economic benefits to water use. The time horizon of the model is one year with 12 periods (months). The following subsections describe the hydrologic, agronomic, and economic components in more detail.

Hydrologic Component

Hydrologic relations and processes are based on the flow network. Major hydrologic relations and processes include: a) flow transport and balance from river outlets/reservoirs to crop fields, and domestic and industrial demand sites; b) return flows from irrigated areas and urban-industrial areas; c) reservoir releases; d) in-stream water uses; and e) groundwater.

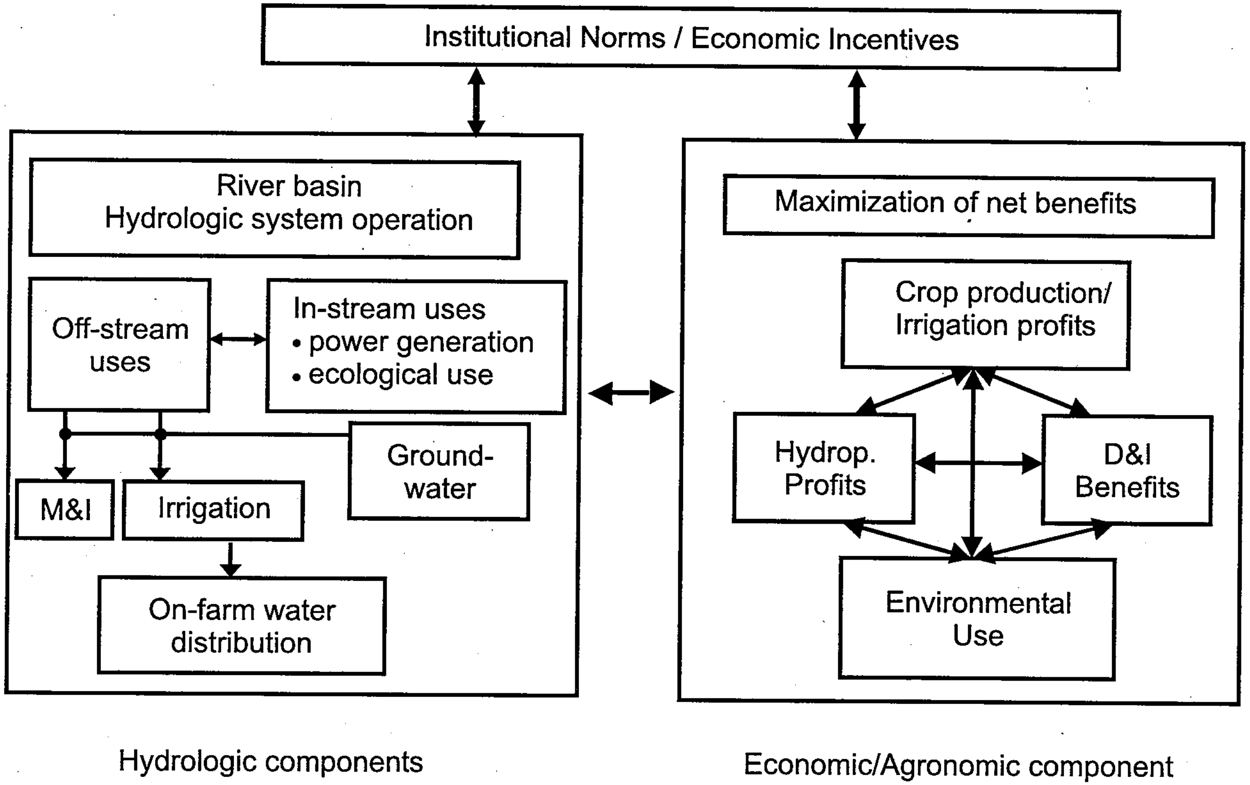
The basic flow balance at a node in the basin network is calculated as:

$$\begin{aligned} &flow\_downstream = flow\_upstream + local\_drainage + \\ &return\_flows - withdrawals - (evaporation)\ losses \qquad (1) \end{aligned}$$

The rainfall-runoff process is not included in the model. It is assumed that runoff starts from rivers and reservoirs. Effective rainfall for crop production is calculated outside of the model, and is included into the model as a constant parameter.

[4]Two irrigation demand sites on the West Vam Co river have so far not been incorporated as there is disagreement whether they form part of the Dong Nai river basin.

Figure 4. Model components, integrated economic-hydrologic river-basin model.



After careful analysis of existing data, it was determined that data were not sufficient for the incorporation of a (shallow) groundwater balance. Missing data include reliable recharge values, transmissivity coefficients from river to groundwater and vice versa, as well as the specific parameters for the groundwater table. As a result, only the exploitation capacity of shallow groundwater was included, and withdrawal estimates as available.

Economic Component

The objective of the model is to maximize the annual net profits from water uses in irrigation, households, industries, and hydropower generation. The objective function is formulated as:

$$Max \quad Obj = \sum_{a} VA(a) + \sum_{m} VM(m) + \sum_{\text{in}} \text{VI(in)} + \sum_{\text{pw}} VP(pw) \qquad (2)$$

where,

VA	net profit from irrigated agriculture
VM	net benefit from municipal water use
VI	net profit from industrial production
VP	net profit from power production
a, m, in, pw	indexes for irrigation, domestic, industrial demand sites and power stations

Crop-Yield Function

In order to establish a relationship between water input and crop yield, a quadratic production function is chosen (see equation 2) due to its properties of decreasing marginal returns to additional inputs and substitutability of inputs.

The quadratic function is expressed as follows:

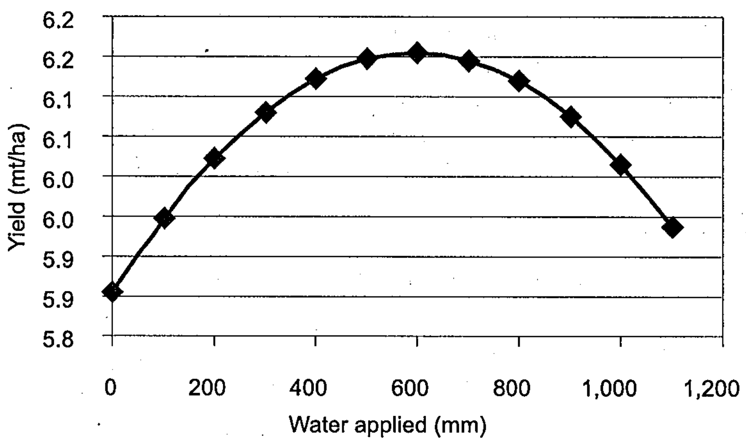
$$y(a,c) = [\alpha_1, \alpha_2, \alpha_3, \alpha_n,] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_i \end{bmatrix} + [x_1 \quad x_2 \quad x_3 \quad x_n] \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{1m} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{2m} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{3m} \\ \gamma_{n1} & \gamma_{n2} & \gamma_{n3} & \gamma_{nm} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_i \end{bmatrix} \qquad (3)$$

where, α and γ are the input coefficients.

The quadratic yield function is estimated using the Generalized Maximum Entropy (GME) approach (Golan et al. 1996; Mittlehammer et al. 2000). GME was developed by Golan et al. (1996) and a comprehensive presentation can be found in the above references. The program that calculates the yield functions was developed by Richard Howitt of University of California at Davis, USA, and Arnaud Reynaud of INRA (Institute National de la Recherche Agronomique), in France. The yield model uses first-order conditions derived from the desired model structure and a yield function as estimating equations. This approach enables the estimation of flexible form yield function parameters in the case of limited small sample information. In this situation, conventional econometric estimates would be restricted by the ill-posed or ill-conditioned data sets. Adaptations to the original Howitt/Reynaud program include usage of cost as inputs instead of physical quantities, redefinition of water inputs to include irrigation water applied from questionnaire observations together with estimates of effective rainfall, and the estimation of yield functions instead of the earlier approach of estimating production functions.

The resulting α and γ coefficients have been incorporated into the basin model. Figure 5 shows an example of the yield function at increasing water application.

Figure 5. Yield function with water as an input, maize winter-spring season.



The net profit function for irrigated agriculture is formulated as:

$$VA(a) = \sum_{c} A(a,c) * y(a,c) * pc(c) - (lc(c) + mc(c) + fc(c) + pec(c) + sc(c)) \quad (4)$$
$$- W(a,c) * pw(c)$$

where,

A	=	area harvested
y	=	yield, calculated in quadratic yield function
pc	=	crop price at farm gate
lc	=	labor cost (family and hired)
mc	=	machinery/animal cost
fc	=	fertilizer cost
pec	=	pesticide cost
sc	=	seed cost
W	=	irrigation water applied
pw	=	water fee per m^3
c	=	idex for crops

Penalty Function

The seasonal crop yield function drives the seasonal water allocation among crops, but cannot distribute the water within the crop growth season according to the water requirements of crop-specific growth stages. In order to achieve consistency between the seasonal yield function and the monthly water balance in the hydrologic system a penalty term is introduced into the objective function that minimizes the difference between the maximum and average crop stage deficit due to water stress for a given crop and demand site. A crop growth stage is defined as one month. As a result, water is being allocated to crop-growing months in relation to the monthly crop-growth deficit.

The function is formulated as:

where,

$$Pen = y(a,c) * A(a,c) * pc(c) * (mdft(a,c) - adft(a,c)) \quad (5)$$

y	=	crop yield
A	=	irrigated crop harvested area
pc	=	crop price
$mdft$	=	maximum stage yield deficit due to water stress by crop and demand site
$adft$	=	average stage yield deficit

with:

$$dft(a,c) = kym(c)\ (1 - Eta(c,a)/ETm(c,a)) \quad (6)$$

where,

dft = monthly stage deficit by crop and demand site
kym = monthly crop yield response coefficient, following Doorenbos and Kassam (1979).
ETa = actual crop evapotranspiration
ETm = potential crop evapotranspiration

Domestic Net Benefit Function

The net benefit function for domestic water uses (*VM*) is derived from an inverse demand function for water. In a first step, a double-log function is estimated based on the household water-demand behavior survey described above separately for connected and nonconnected households. The variables included in the estimation are water use per capita per year; income per capita; and price/cost of water to the user. The estimated function is then extended to other cities and provinces through income and per capita water use shifters.

$$\ln(W) = \theta + \beta \cdot \ln(I) - \varepsilon \cdot \ln(Pw) \tag{7}$$

where,

W = per capita water demand
I = income per capita
Pw = water fee
e = price elasticity of demand
b = income elasticity of demand

The inverse of the demand function is then integrated over the space of W_0[5] - W to estimate the consumer surplus:

$$CS(W) = VM(m) = \frac{e^{(\alpha/\varepsilon)} \cdot Y^{(\beta/\varepsilon)}}{\left(1 - 1/\varepsilon\right)} \cdot \left\{ W(m)^{(1-1/\varepsilon)} - W_0(m)^{(1-1/\varepsilon)} \right\} - W(m) \cdot Pw(m) \tag{8}$$

The income variable was treated as a constant. An example of the net benefit function is shown in figure 6.

Industrial Net Profit Function

Due to sparse data, the industrial net profit function is derived from a double log function, which relates several years of estimated industrial water-use data to industrial GDP for major industrial provinces in the DNRB.

[5]There are no clear guidelines for choosing W_0. Here it is defined as average per capita consumption. Thus, consumer surplus here can only be accrued for consumption levels above average demand. It is not considered crucial in this modeling framework, as allocation is driven based on marginal benefits.

The function is formulated as:

$$\ln(Ip) = \delta + \chi \cdot \ln(W) \quad (9)$$

where,

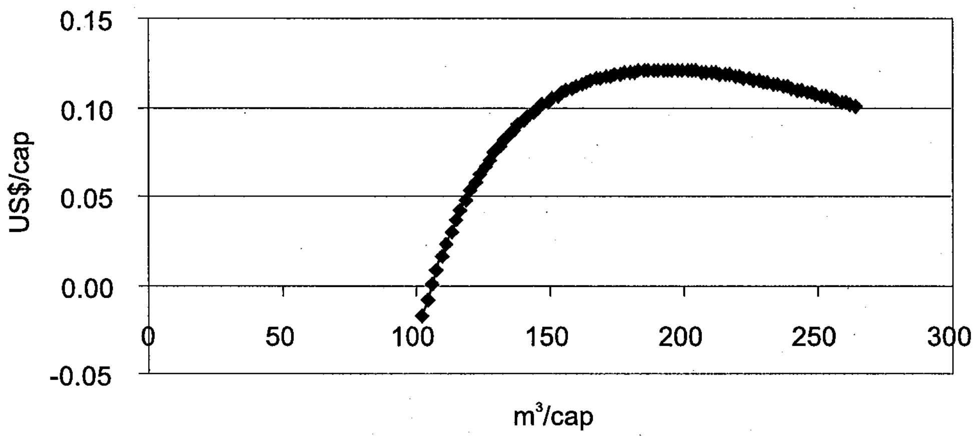
Ip = industrial production (proxied by industrial GDP)

W = water withdrawn

c = *water supply elasticity*

For the net profit function—similar to the domestic net benefit function—only withdrawals over and above average observed or "normal" are included into the calculation. The function is formulated as:

Figure 6. Net benefit function, domestic water use, MBBT, rural areas.



$$VI(in) \quad = \quad (\exp(Ip(in)) - \exp(Ip_0(in))) - (W(in) * Ic(in)) \qquad (10)$$

where,

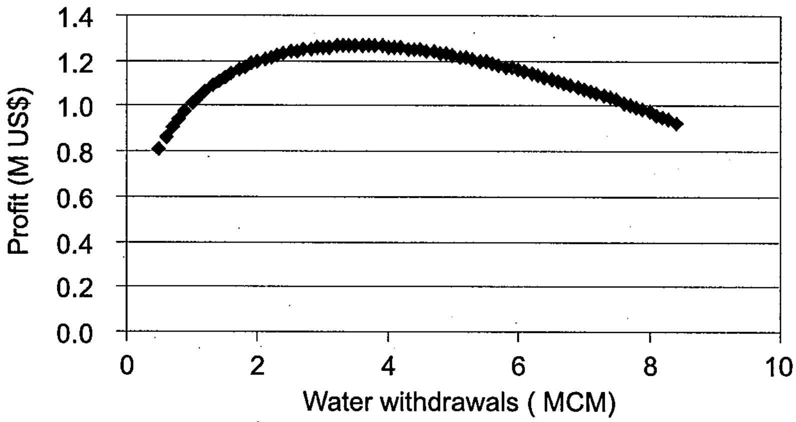
Ip = industrial profit at model water withdrawals
Ip_0 = industrial profit at normal withdrawals
W = total water withdrawn
Ic = industrial withdrawal cost

An example of the net profit function is shown in figure 7.

Hydropower Net Profit Function

To estimate power production, in a first step, power-production efficiency is calculated based on daily release and power production data:[6]

Figure 7. Net benefit function, industrial water use, ex. Bien Hoa, Dong Nai Province.



[6]See also Linsley et al. 1991.

$$eff(pw) = \frac{Pow(pw) * 1000}{Q(pw) * (h(pw) - t(pw)) * 24 * 9.8} \quad (11)$$

where,
Pow = *electricity production ('000 kwH)*
Q = *flow through turbine (MCM)*
h = *head (m)*
t = *tail-water level (m)*

In order to calculate power production, equation (11) is solved for *Pow(pw)* and parameters are adjusted for monthly production. *Q(pw)* and the *h* are decision/intermediate variables in the model.

The reservoir head for power production and the reservoir area to determine net evaporation are calculated based on estimated reservoir topologic equations relating reservoir storage and height, and area and storage, respectively:

$$RST(pw,t) = a(pw) * h(pw,t)\verb|^|3 + b(pw) * h(pw,t)\verb|^|2 + c(pw) * h(pw,t) + d \quad (12)$$

$$RA(pw,t) = e(pw) * RST(pw,t)\verb|^|3 + f(pw) * RST(pw,t)\verb|^|2 + g(pw) * RST(pw,t) + i \quad (13)$$

where,
RST = reservoir storage (MCM)
RA = reservoir area (km^2)
a-i = coefficients
h = head (m)
t = period

Profit from power production *(VP)* is calculated as a linear function, multiplying power production *(Pow)*[7] with the difference between power selling price *(pp)* and power production cost *(pc)* for each hydropower station. The calculation of net profit from hydropower production does not include capital costs, which are considered sunk costs in this model.

$$VP(pw) = Pow(pw) \cdot (pp(pw) - pc(pw)) \quad (14)$$

[7]The power variable here is for million kwH.

Model Data and Calibration

The model is calibrated to 1999/2000 data. In the following section, data sources for the model are briefly described and selected baseline results are compared with observed/actual data. Further calibration efforts, under the assumption that the actual observed situation reflects the optimal outcome for the baseline, will be implemented in the next modeling phase.

Hydrologic Data

Source flow was determined by the hydrology division of the Sub-Institute for Water Resources Planning (SIWRP) based on a rainfall-runoff model called RRMOD or Rainfall-Runoff Model based on rainfall during 1978–1998 for a total of 37 nodes. Together with the withdrawal nodes, altogether 82 nodes are included in the model. Runoff at 25 percent, 75 percent, and 90 percent probability levels was also estimated by SIWRP. Total discharge amounts to 47.065 BCM. As these data are ex-post depletion,[8] estimated actual depletion is added to these observed natural flows. Approximately 4 BCM are added. Baseline model discharge amounts to a slightly larger 48.378 BMC.

A minimum in-stream flow requirement for all river reaches in the basin of 10 percent of source flow has been included to guarantee basic river habitat. In addition, the DNRB has specific minimum flow requirements to control saltwater intrusion and secure a safe drinking water supply for the lower basin, chiefly HCMC. A minimum downstream flow requirement of 85 m^3/sec has been included on the Dong Nai river at the Binh An water-supply plant. On the Sai Gon river a minimum flow requirement of 25 m^3/sec was included at the location of the future Ben Than water-supply plant.

Shallow groundwater capacity is largest in the Lam Dong province and lowest in Long An (only including the basin area).

Agricultural Data

The parameters for the crop-yield function were collected by the Sub-National Institute for Agricultural Planning and Projections (Sub-NIAPP) in an extensive farm household survey covering 700 households in the 11 provinces of the basin. The survey covers crops from the summer-autumn season of 1999 to the winter-spring season of 2000. Functions were estimated for the major annual crops (bean, maize, peanut, sugarcane, tobacco, and vegetables) and perennial crops (coffee, fruit trees, other trees, and pepper) in the basin; annual crops are separated by season (winter-spring, summer-autumn, and rainy season). Moreover, rice and vegetables are further subdivided by region (coastal area, mountainous area, and lowland area). The input variables incorporated are in US$/ha: labor, machinery, fertilizer, pesticides, seeds, and water. Family labor is valued at the prevailing wage rate stipulated by the farm households. Water includes both irrigation water applied and effective rainfall. Whereas irrigation water

[8]Depletion refers to water that cannot be reused in the system.

applied was solicited in the survey, effective rainfall was estimated based on daily rainfall data prevailing during the survey implementation.

Irrigation service fees (ISF) in Vietnam for public systems are decided at the provincial level following national government guidelines. ISF are area-based and can vary by crop, season, and type of irrigation water supply (gravity or pump irrigation). In some cases, fees differ by district. Currently, fees only partially reflect the scarcity value of water. Fees are typically higher for pump irrigation, but also typically lower for rice, which consumes relatively more water. For the study here, irrigation costs include all costs related to irrigation provision, including family and hired labor, ISF, and private pumping cost. Irrigation costs from the survey have been divided by the quantity of water applied to proxy volumetric charges. According to survey observations, the water fee is largest for vegetables in the winter-spring and summer-autumn seasons in coastal and mountainous provinces, and lowest for rice crops in the rainy season. Currently, only one average fee per crop type is incorporated in the model. However, the averaging of irrigation costs across different climatic conditions in the basin causes negative profits from irrigation in many irrigation zones. Another reason for negative profits is the valuation of family labor at the prevailing farm wage rate. As a result, for the baseline, only 50 percent of the surface irrigation fee is applied. The groundwater pumping fee is set at 0.07 US$/m^3, which reflects typical pumping costs.

There are no consistent databases for irrigated area and irrigation sources in Vietnam. Irrigation and Drainage Management companies collect data for public systems, but even these data can be confusing as distinctions between potential command area, actual area served, and area contracted are not always clear. Detailed data, by season and type of irrigation, are usually only available for paddy. Upland crops are not separated. Private (pump and well) irrigation is not recorded. Sub-NIAPP estimates gross irrigated area for 1999/2000 at 819,136 ha, whereas SIWRP estimates it at 781,349. These estimates do not include irrigation areas located in the west Vaico river system. For this analysis, upland crops were distributed according to statistical yearbooks and survey results. It was assumed that only perennial crops are irrigated. The groundwater irrigation shares have been derived from Sub-NIAPP data.

The yield function and costs are applied to the gross irrigated area for 1999 of 759,480 hectares.[9] Area is constrained between 0.4–1.2 of the actual area irrigated during 1999/2000. the total area at each irrigation demand site is constrained to actual levels.

Only sparse data are available for return flows in the basin. According to Water Resources University (1999), overall return flows in Ninh Thuan average 20.3 percent. Other reports document 19.96–23.2 percent for the Mekong delta (similar soils as in Long An part of Tay Ninh) and 21.2 percent in the highland areas. Recent canal-lining efforts in the DNRB and elsewhere in Vietnam are expected to increase distribution efficiencies from 70 percent to 90 percent (personal communication, Ninh Thuan and Cu Chi Irrigation and Drainage Management Companies). In the model, return flows are estimated to include one-third of the percolation on the crop fields (from both surface water and groundwater withdrawals), and one half of the losses occurring during distribution and conveyance. Average return flows in the model thus amount to 26.7 percent.

[9]Adjustments to the SIWRP area included treating sugarcane as an all-year crop and deletion of irrigated areas in the wet season, where irrigation is not considered necessary, based on CROPWAT estimates.

Domestic Water Use Data

There is no database for domestic water use in the basin. Therefore, data were collected separately from water supply companies.[10] Water-loss rates were applied for surface water supply based on the data collected from the public-supply system. They varied from an average loss rate of 19 percent for Ba Ria-Vung Tau (BRVT) to 49 percent in the Trang Bang, Tay Ninh Province. Water tariffs from public supply companies were included as available. About half of the companies apply progressive tariffs. Average tariffs varied from VND 1,600/m^3 (US$ 0.11/m^3) for Long An Province to VND 2,529/m^3 (US$ 0.18/m^3) in Da Lat City, Lam Dong Province. For individual pumping and most rural domestic water uses, a supply cost of US$ 0.1/m^3 was assumed.

According to the information by the water supply companies in the basin, deliveries in 1999/2000 amounted to 683,000 m^3/day, 83 percent of which was supplied from surface water. This translates into an average delivery of 48 l/cap/day. However, public water supply companies serve only about 60 percent of the population of major cities, and people with household connections consume, on average, substantially more than nonconnected households. HCMC's water supply company, for example, served 55 percent of the city's population in 2002. For those districts and areas without public supply, a minimum supply standard of 40–50 l/cap/day was assumed. This results in a total domestic water supply of about 920,500 m^3/day and per capita supply of 64 l/day.

The parameters for the domestic benefit function were estimated separately for connected and nonconnected households based on the 1995 household water demand behavior survey carried out by GKW/SAFEGE (1996).[11] The survey was carried out in the 12 inner and 4 peripheral districts of HCMC. The parameters estimated for the domestic benefit function are shown in table 3. The price and income elasticities estimated were then applied to other districts in the basin, following adjustments for rural-urban shares (to which nonconnected and connected parameters were applied), rural-urban incomes, rural-urban water prices, and rural-urban consumption shares. In the model, total domestic water demand is constrained between 0.6 and 2 times the observed and estimated water usage.

Industrial Water Use Data

There is no agency in charge of monitoring industrial water-use data. Estimates of industrial water use in the Dong Nai basin have ranged from 130 to 2,500 million m^3 per year (Ngoc Anh 2000; Boggs). For this study, industrial water use was collected for the industrial zones of the four major industrial provinces in the basin (Ba Ria Vung Tau, Bin Duong, HCMC, and Dong Nai). However, data were available only for some of the zones. In addition, substantial industrial

[10]Binh Phuoc has no water supply company and no data were collected in Dak Lak province, as only two rural districts are included in the basin area.

[11]GKW and SAFEGE are German and French consulting companies, respectively, which carried out ADB TA 2000-VIE.

Table 3. Household Survey, Sample Information

	Connected HH	Non-connected
Constant	-0.36846	-0.66096
	(2.1)	(2.9)
ln(income)	0.40434	0.32252
	(12.4)	(4.5)
ln(price)	-0.17327	-0.30259
	(3.0)	(10.0)
Av. Demand (m^3/m/cap)	4.9	2.4
Av. Price(US$/$m^3$)	0.11	0.67
Av. Income (US$/m/cap)	36.9	24.8
Observations (No.)	894	187

Note: Absolute value of t-statistics in parentheses. Coefficients from double-log function. Av. = Average.

production takes places outside of designated industrial zones. Industrial water supply was also collected from municipal water-supply companies in the various provinces in the basin, when available. As these data were still not sufficient, industrial water use was estimated based on the water-use coefficients for industrial products shown in table 6 in Boggs 1995. The calculated industrial water-use data for the years with available data are shown in table 4. The regression estimates for industrial water use and GDP by province are shown in table 5.

In 1999, the total net industrial water demand was estimated at 287 million m^3, 44 percent of which was delivered from surface-water sources and the remainder from private or industrial zone-managed wells. The water tariff that public water companies charge to industries varies little among provinces and is usually a flat rate. Among the provinces with available data, the rate is lowest in the Long An Province at VND 2,600/m^3 (US$0.19/$m^3$) and highest in Binh Thuan Province at VND 4,500/m^3 (US$0.32/$m^3$). For modeling purposes, water abstractions are constrained between 0.7 and 1.8 of estimated actual withdrawals.

Hydropower Data

Historic daily reservoir release data as well as power production for the major existing reservoirs in the DNRB, Da Nhim, Thac Mo, and Tri An, were obtained from the Power Engineering Consulting Company 2 (PECC2) in HCMC for at least three consecutive historic years. The Ham Thuan and Da Mi power stations started operating only during 2000. Therefore, no historic records could be obtained. Design parameters were used for these two hydropower stations.

Other parameters incorporated include dead and maximum storage, maximum turbine flow, power-production efficiency, and the area-storage and elevation-storage relationships. Moreover, reservoir operation curves that set monthly standards for minimum reservoir height and storage to secure minimum water availability as well as maximum reservoir height for flood control have been incorporated as constraints into the model. The introduction of the operation

Table 4. Industrial water use, DNRB provinces, 1995-1999 (million m^3).

	1995	1996	1997	1998	1999	1995-1999 (%/yr.)
Ba Ria Vung Tau	14.0	28.7	38.6	45.4	45.8	34.5
Binh Duong	12.4	26.9	47.9	59.4	94.0	65.9
Binh Phuoc	0.5	0.5	0.5	0.7	0.9	17.5
Binh Thuan	0.5	0.7	0.8	0.9	1.2	22.4
Dac Lac	6.6	6.8	7.4	8.2	8.2	5.6
Dong Nai	na	252.9	269.6	246.5	280.4	3.5
HCMC	177.0	174.6	212.6	283.7	295.6	13.7
Lam Dong	1.1	2.1	3.8	3.9	3.6	34.0
Long An	6.9	101.0	99.9	94.9	100.2	95.1
Ninh Thuan	0.9	1.1	1.5	1.9	2.4	26.3
Tay Ninh	3.3	3.0	3.4	4.3	6.0	16.4
Total	223.3	598.4	686.0	749.8	838.2	39.2

Note: Calculation refers to administrative, not basin boundaries; calculation based on water use coefficients for industrial products, as presented in Boggs 1995. Data on industrial products included in provincial yearbooks varies by province and are therefore not necessarily consistent across provinces.
Source: Boggs 1995 and various provincial statistical yearbooks.

Table 5. Regression estimates for GDP and water input.

	Intercept	Water coefficient
Ba Ria-Vung Tau	0.32701	1.59029
Binh Duong	0.84041	1.06091
Binh Thuan	3.58741	1.45063
Dong Nai	3.38966	0.45416
HCMC	0.83447	1.21217
Long An	2.12296	0.46874
Tay Ninh	2.69079	0.72138

Note: Coefficients from double-log estimates.

curves significantly constrains tracing out optimal reservoir-operation strategies and, as a result, hydropower profits are constrained within a narrow margin. Reservoir-operation curves are not adhered to religiously in the basin, particularly during very high (2000) and low flow years (1998).

Hydropower production costs, supplied by PECC2, for the major stations, range from US$ 0.012/kWh for the Thac Mo station to US$0.033 for the Ham Thuan and Dami stations; and electricity selling prices range from US$0.038/kWh for Tri An to US$0.07/kWh for the Da Nhim station. For analysis purposes, it is assumed that hydropower profits accrue to those provinces where the reservoir is located.[12]

The model has been coded in the GAMS modeling language, a high-level modeling system for mathematical programming problems. The CONOPT2 solver for highly nonlinear problems has been utilized.

Baseline Results

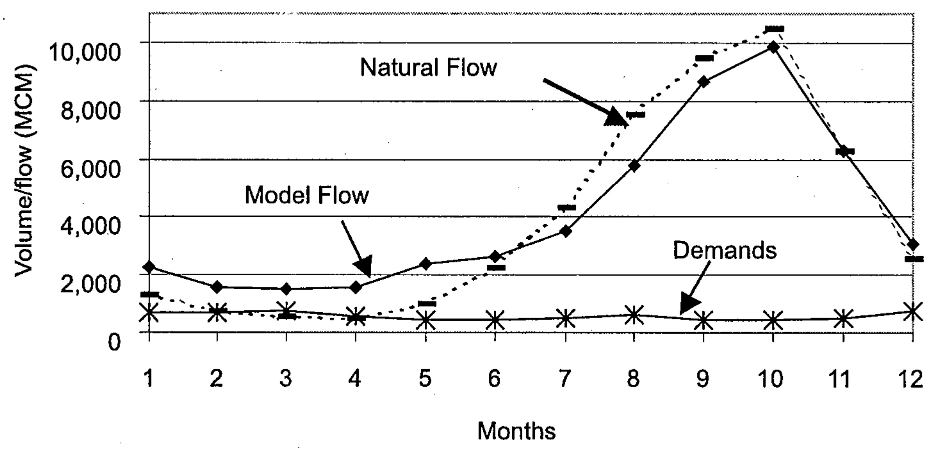
In the baseline, water withdrawals to off-stream demand sites and in-stream flow demands are driven by the objective of maximizing basin benefits from water use subject to a series of physical and system-control constraints as well as minimum in-stream and downstream flow requirements.

The total off-stream water withdrawals are estimated at 3,465 million m^3, 7.4 percent of the total runoff. Altogether 2,312 million m^3 are withdrawn for irrigation, 542 million m^3 for domestic uses, and 612 million m^3 for industrial uses. Minimum flow requirements for drinking water on the Dong Nai and Sai Gon rivers account for a further 3,469 million m^3. In addition, the total groundwater abstractions amount to 284 million m^3 or 2.8 percent of the total shallow groundwater capacity. About 100 million m^3 are pumped for irrigation, 158 million m^3 for domestic uses, and 23 million m^3 for industrial uses. The total power production amounts to 5,284 GWh.

Figure 8 shows the distribution of natural flows, model flows, and water demands across the year for the baseline solution. A few observations can be made based on this graph. First, it clearly shows the large variation in flow between the dry and rainy seasons, even after the construction of the three major reservoirs in the basin (model flow). Second, the graph shows that the construction of these reservoirs has been vital to prevent water shortages in the dry season, as demands surpass natural (prior to reservoir) flows during March and April, by 214 million m^3 and 56 million m^3, respectively. Finally, existing reservoir storage can accommodate only about a doubling of total demands during the dry season, and plans for future reservoirs, which are chiefly for hydropower production, can only accommodate some additional dry-season demands (see also the 2010 scenario discussed later in this paper).

[12]This is an issue in the case of the already existing Da Nhim and the future Dai Ninh reservoirs; the reservoirs are located in Lam Dong Province, but the hydropower stations are in Ninh Thuan and Binh Thuan provinces, respectively.

Figure 8. Baseline flows and withdrawals.



Based on this graph, the DNRB can be characterized as an "open" river basin, where excess water is available, over and above all committed legal, ecological and environmental requirements, even during the dry season. However, the basin will likely soon approach a "semi-closed" state, where sufficient water resources are available during the rainy season, but off-stream and in-stream water needs compete with each other during the dry season. In the so-called "closed" basins, finally, there is no excess water flowing out of the basin; all water resources are committed to use (Keller et al. 2000). The latter state is unlikely to occur in the Dong Nai basin.

Table 6 shows the baseline profits by province in the basin. The total profits add to US$ 2,123 million; 48 percent from industry, 29 percent from domestic uses, 15 percent from irrigation, and 7 percent from hydropower production. HCMC achieves the largest profit from water use. Industrial water-use profits are concentrated in the lower basin area, chiefly HCMC, Dong Nai, and Tay Ninh provinces. Benefits from domestic water use are by far the largest in HCMC. Irrigation profits are largest in the Lam Dong and Tay Ninh provinces, followed by Binh Phuoc and Ninh Thuan. Hydropower profits are the largest for Ham Thuan-Da Mi station, followed by Da Nhim in the Lam Dong Province. This result reflects the large participation of nonagriculture sectors in the basin water economy, although irrigation is by far the largest water user in the basin.

Table 6. Baseline scenario, profits from water use.

	Irrigation	Domestic	Industry	Hydropower	Total
Ba Ria - Vung Tau	10.7	12.7	55.7	79.1	—
Binh Thuan	28.5	30.7	19.3	54.8	133.3
Ninh Thuan	36.2	7.9	54.7	—	98.7
Coastal	75.3	51.3	129.8	54.8	311.2
Binh Phuoc	44.0	16.7	—	29.2	89.8
Dak Lak	8.4	0.4	—	—	8.8
Lam Dong	61.0	77.1	—	39.9	178.0
Mountain	113.3	94.3	—	69.1	276.7
Binh Duong	10.7	26.1	45.8		82.6
Dong Nai	15.7	78.7	265.8	31.6	391.7
HCMC	19.6	335.0	285.0	—	639.7
Long An	26.6	17.8	35.7	—	80.2
Tay Ninh	62.0	11.4	267.5	—	340.9
Lower Basin	134.6	469.0	899.7	31.6	31.6
Basin Total	323.3	614.5	1,029.5	155.5	2,122.8

Table 7 shows the difference between actual and model area allocation. According to the model result, the total area is lower by 6,063 hectares. The largest percentage decline occurs for sugarcane, whereas the largest absolute net decline occurs for rice. However, among the various paddy crops, winter-spring and summer-autumn paddy in the lowland areas actually increase in actual area, as does rainy season paddy in the coastal area. Water withdrawals (net of conveyance and distribution losses) are by far the largest in February and March at around 225 million m^3. Withdrawals are the largest for perennial crops and paddy. Coffee withdrawals add to 354 million m^3 or 26 percent of the total withdrawals. All paddy crops taken together account for 686 million m^3 or 50 percent of the total withdrawals. Crops grown during the rainy season and short-duration crops show the lowest withdrawal quantities.

The variation in the contribution of rainfall to water consumption varies substantially for irrigated crops, and depends on location, and on planting and harvesting dates, among other factors. Water application per hectare is largest for the perennial crops: coffee, fruit trees, other trees (largely grapes in the Ninh Thuan Province), pepper and sugarcane. However, effective rainfall might actually be lower for perennial crops as they already take up substantial shallow groundwater through their extensive root zone. Paddy crops rank second in water application. Vegetables, on the other hand, have the lowest crop-water demands. The share of effective rainfall in total crop-water consumption is above 50 percent for most of the crops. It is only lower—accounting for about a third of the total consumptive use—for several dry-season planted crops, like bean, peanuts, rice, and tobacco.

Table 7. Irrigated area, actual and baseline result.

	Area, 1999/2000 (hectare)	Change in area, model	Change (%)
Bean	6,294	1,203	19
Coffee	101,041	4,525	4
Fruit tree	19,800	3,105	16
Maize	13,906	2,781	20
Other tree	1,603	321	20
Peanut	38,652	7,730	20
Pepper	4,591	918	20
Rice	494,983	-38,368	-8
Sugarcane	12,650	-1,470	-12
Tobacco	2,450	490	20
Vegetables	63,510	12,702	20
	759,480	-6,063	-1

Note: 20% denotes the upper limit in area change.

Table 8 presents the net profit per hectare and the productivity of irrigation water for the basin crops. Net profits per hectare are largest for the category "other tree" (largely grapes), followed by pepper, and some of the vegetable crops. Profits per hectare are lowest for several of the rice crops and sugarcane. The productivity of irrigation water, defined as US$/m^3, depends on both the profitability of the crop and its need for irrigation water. Baseline results indicate that water productivity is highest for vegetable crops,[13] followed by pepper, bean grown during the rainy season, and the category of "other trees." Water productivity is lowest for sugarcane, followed by various paddy crops.

Figures 9–12 present the marginal values for the various water uses in the basin. Figure 9 shows the monthly marginal value for irrigation water averaged across the basin-demand sites. The shadow price is largest in March at US$0.014/m^3 and averages US$0.006/m^3 across the year (without taking negative values into account).[14] Figure 10 shows the marginal value of water in hydropower production averaged across power stations. The marginal value is highest during the dry season and almost mirrors the discharge curve of the basin. It averages US$0.02/m^3 and variations across the year are very small due to the operation curve imposed in the model. The marginal value curves for domestic and industrial uses (figures 11 and 12) are similar in form, but differ substantially in value. The marginal value for domestic uses

[13]The very high water productivity of coastal rainy season paddy is due to very low irrigation water demand for that particular crop.

[14]Negative shadow prices are due to the lower bounds in area set in the model.

Table 8. Baseline scenario, net profit per hectare and productivity of irrigation water by crop.

	(US$/ha)	(US$/m³)
Other trees	7,986	0.940
Pepper	5,484	1.558
VegiDXc	4,335	0.724
VegiMUAc	4,275	3.739
VegiHTc	4,073	0.603
TobaccoDX	2,506	0.498
BeanMUA	1,599	1.131
VegiMUAm	1,592	6.448
VegiHTm	1,558	1.655
BeanHT	1,506	1.051
Fruit trees	1,215	0.189
VegiDXu	1,015	0.448
VegiDXm	875	0.275
VegiHTu	839	0.351
VegiMUAu	666	0.777
Coffee	636	0.113
PeanutDX	299	0.105
MaizeDX	203	0.061
RiceDXc	180	0.047
RiceHTc	180	0.106
MaizeHT	166	0.119
RiceHTm	139	0.035
PeanutHT	136	0.200
RiceDXu	114	0.041
Sugarcane	109	0.024
RiceDXm	105	0.032
RiceHTu	105	0.029
RiceMUAm	94	0.105
RiceMUAu	92	0.029
RiceMUAc	70	67.927

DX = winter-spring, HT = summer-autumn, MUA = rainy season; c = coastal area (BRVT, Binh Thuan, and Ninh Thuan; m = mountainous area (Binh Phuoc, Dak Lak, and Lam Dong provinces); u = lower basin (Binh Duong, Dong Nai, HCMC, Long An, and Tay Ninh).

averages US$0.18/m^3 and peaks in February at US$0.29/ m^3. The marginal value for industrial use is much higher, averaging US$13/m^3 and peaking at US$13.5/m^3 in February. This very high marginal value is due to the current specification of the industrial water-use function that directly links water as an input with industrial GDP as an output.

Alternative Scenarios

Sensitivity Analyses

Sensitivity analyses are carried out to test the robustness of baseline results. Parameters tested include changes in inflow level, field application efficiency, irrigation fee, domestic water tariff, industrial tariff and selected crop prices. All in all, model results shift very little due to changes in those parameters (unless bounds incorporated into the model are relaxed or shifted); another indicator for the relative water abundance in the basin. Results are presented in table 9.

Figure 9. Maginal value, averaged across sites, irrigation.

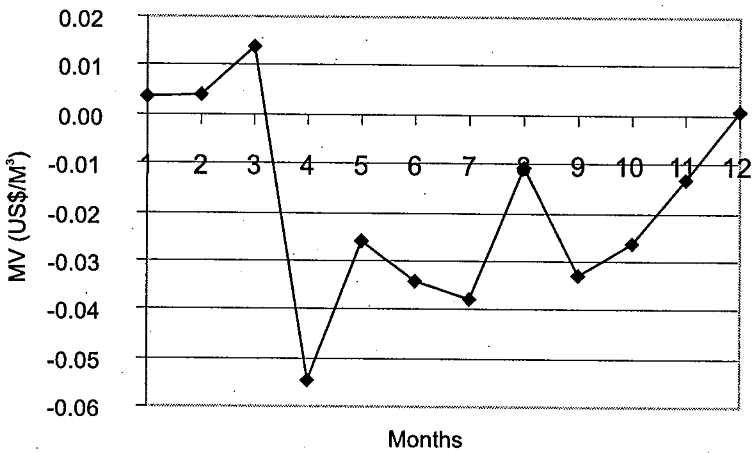


Figure 10. Marginal value, averaged across stations, hydropower.

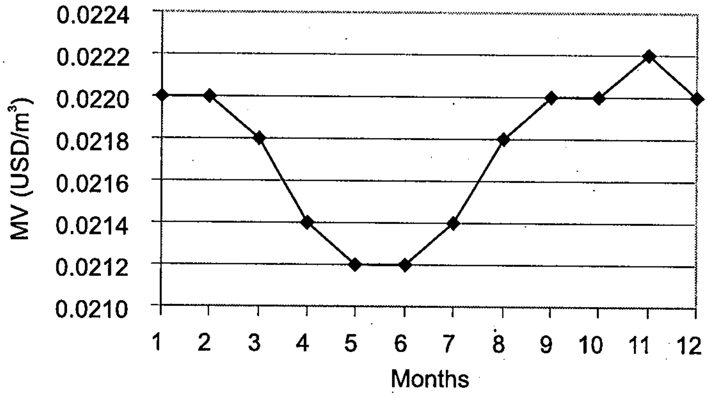


Figure 11. Marginal value, averaged across sites, domestic uses.

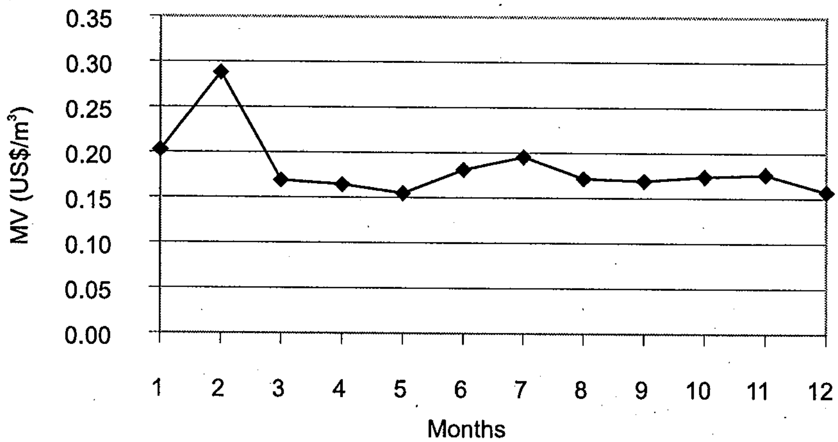
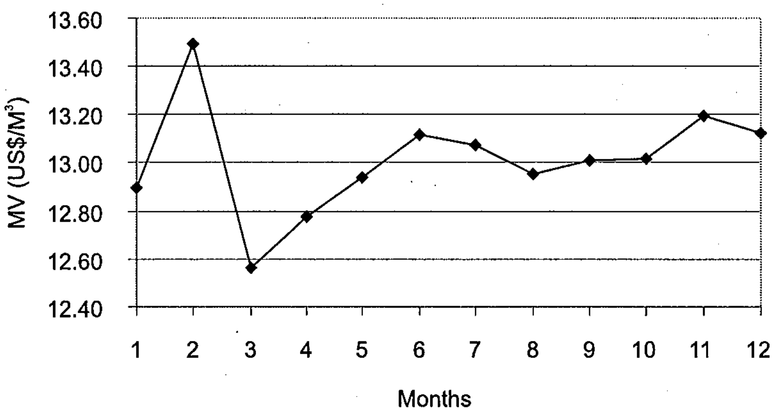


Figure 12. Marginal value, averaged across sites, industrial uses.



A high-flow year (inflows and effective rainfall at the 25% probability level) leads to a substantial increase in basin profits of 21 percentage points. Profits increase across sectors, led by industry, due to the high marginal value of water used in industry. At the same time, agricultural water withdrawals, including pump irrigation, decline due to the availability of additional effective rainfall.[15]

Inflows and effective rainfall at the 75 percent probability level, simulating a low-flow year, reduce total profits by less than 1 percent. However, irrigated area declines by 3 percentage points and agricultural withdrawals by 5 percent compared to baseline levels. In addition, hydropower profits drop by 9 percentage points due to reduced inflows into reservoirs. Finally, due to decreased surface flows, industrial groundwater pumping increases by 17 percent over baseline levels.

A further reduction in inflow levels reduces total profits only slightly more. Hydropower production is again affected most, declining to 82 percent of baseline levels. Irrigation profits drop by 2 percentage points. The share of groundwater pumping increases, but total irrigation withdrawals decline by 13 percent compared to baseline levels. Irrigated area declines by only 4 percent, indicating that those crops that consume most of the water have been taken out of production. In addition, pumping of both industrial and domestic groundwater increases, whereas total withdrawals decline.

[15]These results are based on a relaxation of upper bounds for withdrawals.

Table 9. Sensitivity analyses, various parameters.

Parameter	Levels/ values	Irrigation profit	Domestic benefit	Industiral profit	HP profit	Total profit	Irrigation area	Total withdr	Agriculture pumping	Total dom withdr	Domestic pumping	Total industrial withdr	Industrial pumping
Inflow/Eff. Rain	25% prob.[a]	108.23	112.78	131.32	105.72	120.56	106.99	98.98	90.83	130.41	132.35	111.84	126.85
	75% probability	99.71	100.00	100.00	91.45	99.33	96.98	94.71	95.42	100.02	100.96	99.84	117.31
	90% probability	97.69	99.91	100.00	81.67	98.28	95.65	86.56	105.60	99.03	109.32	99.50	154.28
Irrigation	0.5[b]	97.33	100.00	100.00	99.16	99.53	93.35	113.86	113.11	99.99	100.05	100.00	100.00
Efficiency	0.9[b]	101.63	100.00	100.00	100.45	100.28	103.89	92.02	93.28	100.00	100.00	100.00	100.00
Irrigation water price	zero	123.11	100.00	100.00	100.00	103.52	116.20	330.65	163.58	99.57	104.01	99.91	109.24
	water applied	95.71	100.00	100.00	100.00	99.35	91.75	78.69	98.90	100.00	100.00	100.00	100.00
	full cost	89.36	100.00	100.00	100.51	98.42	83.28	47.29	105.80	100.00	100.00	100.00	100.00
Domestic water price	Zero	100.00	102.12	100.00	100.00	100.61	100.00	100.00	100.00	100.20	100.00	100.00	100.00
	2*base	100.00	97.89	100.00	100.00	99.39	100.00	100.00	100.00	99.33	100.00	100.00	100.00
	3*base	100.00	95.79	100.00	100.00	98.78	100.00	100.00	100.00	98.52	100.00	100.00	100.00
Industrial water price	Zero	100.00	100.00	113.33	100.00	106.46	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	2*base	100.00	100.00	86.67	100.00	93.54	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Coffee/Pepper price	In 1998	135.01	100.00	100.00	100.00	105.33	100.23	99.54	99.60	99.97	100.66	100.00	100.00
	In 2001	72.08	100.00	100.00	101.41	95.85	92.33	88.16	86.39	100.00	100.00	100.00	100.00

Note: [a]Upper bounds were relaxed for the high flow scenario. [b]Field application efficiency, baseline: 0.7; total withdrawals include pumping. withdr = withdrawals; dom = domestic.

In the baseline scenario, field application efficiency is estimated at 0.7, that is, 70 percent of the water applied at the field level is used beneficially by the plant. When field application efficiency is reduced to 0.5, total basin profits barely decline. Profits from irrigated agriculture drop by 3 percent, and irrigation withdrawals increase by 14 percent. As a result, hydropower profits decline slightly by 1 percent. On the other hand, if the irrigation efficiency is increased to 0.9, profits from irrigation increase to 102 percent of baseline levels, irrigation withdrawals drop to 92 percent of baseline levels, and irrigation areas increase to 104 percent of initial values. Other sectors remain basically unaffected.

As discussed above, the irrigation supply cost used here is a broader concept, incorporating actual costs as well as labor cost for irrigation. In the baseline, an average fee by crop is used for consumptive water use. The fee is set at 50 percent of survey levels , to allow for positive profits even in those basin areas where application levels are high. The pumping fee is set at US$0.07/m^3. For the sensitivity analysis, the irrigation fees are set alternatively to zero, to the total water-application level, and then to the level of survey observations for applied (prior to field application efficiency) water. At a water price of zero (including all the components specified above), irrigation profits increase to 123 percent of baseline levels, and total profits by 4 percent. Irrigation withdrawals increase to the very high level of 331 percent over baseline withdrawals, and irrigated area increases to 116 percent of the baseline area. The industrial and domestic sectors compensate for slight declines in surface withdrawals, due to the increased competition with irrigation withdrawals, by means of increased groundwater abstractions. At the "full" irrigation cost, profits from irrigated agriculture decline to 89 percent of baseline levels, and irrigation withdrawals drop by more than half. As the pumping costs increase by a relatively smaller amount, pumping increases slightly. Finally, irrigated area decreases by 17 percent. Other sectors are not affected. Increases and reductions in the domestic water price lead to small shifts in domestic profits and a very small decline in domestic surface-water withdrawals. In the industrial sector, withdrawal levels are unchanged under a doubling of the water supply cost, but profits decline to 87 percent of baseline levels.

Several major agricultural commodities experienced sharp declines in Vietnam and elsewhere over the past few years. Table 10 shows the change in farm-gate prices for selected irrigated agricultural commodities in the Dong Nai river basin. Although the rice price in Vietnam has dropped significantly in the Mekong delta, prices in the Dong Nai basin remained stable due to the relatively lower quantity and higher quality of rice produced. To see the impact of recent price changes on farmer incomes, alternative simulations are carried out for the 1998 and 2001 coffee and pepper prices. Converted to US dollars, the prices implemented in the model are US$1,033/mt, US$647/mt, and US$372/mt, for 1998, survey (1999/2000), and 2001, respectively, for coffee—a drop by a factor of 2.7 over 3 years—and US$4,590/mt, US$3,434/mt, and US$1,149/mt for pepper, a drop by a factor of 4 over the period. The results of the alternative simulations are shown in table 9. If the 1998 coffee and pepper prices would prevail, irrigation profits would increase to 135 percent over baseline levels, and total basin profits by 5 percent. Coffee area increases by 6,000 hectares, whereas pepper has already reached the upper bound in the baseline. In the case of 2001 coffee and pepper prices, profits from irrigated agriculture dropped to 72 percent of baseline levels, and total profits declined to 96 percent. Irrigated area shrank by 8 percent, and irrigation withdrawals by 12 percent, supporting a slight increase in hydropower production. Coffee area sharply declined by 60 percent to 42,000

Table 10. Price changes for selected irrigated agricultural commodities, Dong Nai basin (VND/kg).

	1997	1998	1999	Survey*	2001
Pepper		60,000	33,000	48,014	17,000
Coffee	22,000	13,500	9,000	9,051	5,500
Rice	1,650	1,650	1,650	1,530	1,650

Note: Survey was implemented for April 1999–April 2000.
Source: Data for 1997–1999 and 2001 provided by Sub-NIAPP.

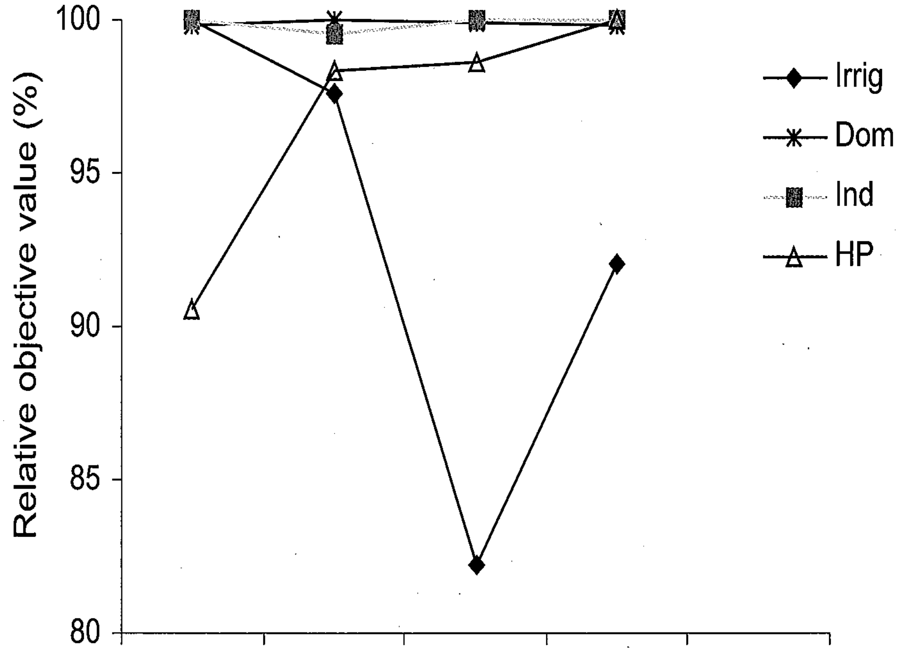
hectares, whereas area planted to pepper declined only slightly by 147 hectare or 3 percent. This differing reaction to changes in crop prices was due to the larger profit margin for pepper (see also table 8).

Trade-off Analysis

In order to show potential trade-offs among the competing objectives of irrigation, domestic and industrial uses, and hydropower production, a trade-off analysis is carried out based on the weighting method. This method is implemented here by running a separate scenario for each primary objective, that is, for irrigation, domestic benefits, industrial profits and hydropower profits. The primary objective in this case is multiplied by a factor of 100 while the other objective functions remain unchanged. These scenarios are run for a low-flow scenario (90% probability level) to better demonstrate potential trade-offs. Overall profits from water uses decline under each of these alternative runs, albeit by very small amounts. The largest decline occurs for the hydropower scenario, but equals just 1 percent of total profits. Scenario outcomes are shown in figure 13. The result from the primary objective function in each scenario was scaled to 100. The curves for the individual objective functions show how they fare under the various primary objectives listed on the x-axis.

Clearly, the largest trade-off occurs for irrigation. When domestic uses are the primary objective, irrigation profits decline by 2.4 percent; under industrial preference, irrigation incomes drop by 18 percent, and when hydropower production is favored, irrigation profits decline by 8 percent. Irrigation is most affected by preferential treatment of other sectors due to the relatively lower value of water in agriculture and the large quantities of water involved in irrigated agriculture. There are also slight trade-offs between hydropower production and other sectors. When irrigation is the primary objective, hydropower profits decline to 91 percent of the maximum potential level; when domestic or industrial uses are favored, profits drop by 2 percent. The decline in hydropower production is due to the increased water depletion for irrigated agriculture. There are only very minor trade-offs for domestic uses. Industrial water use is the least affected by trade-offs from other sectors, due to the large marginal value of water in the sector.

Figure 13. Trade-off analysis among competing objectives.



Note: Inflows and effective rainfall at 90% probability level.

Water Allocation and Use by 2010

Model Data

By 2010, the following reservoirs are expected to be constructed: Can Don, Sroc Phu Mieng, and Phuoc Hoa on the Be river, Dai Ninh, Dong Nai 3, and Dong Nai 4 on the Dong Nai main stream, and Song Luy reservoir on the Luy river in the coastal area. This will increase hydropower capacity to 2,171 megawatts and annual power production is expected to increase to 8,507 gigawatt hours. Total planned investment costs are 1,672 million US dollars.[16]

Phuoc Hoa will release a maximum of 50 m^3/sec to the Dau Tieng reservoir on the Sai Gon river and a minimum of 14 m^3/sec to the Be river, and Dai Ninh will release a maximum of 20 m^3/sec to the Luy river. Minimum in-stream flows by 2010 will increase to 110 m^3/sec at Binh An on the Dong Nai river and to 30 m^3/sec at Ben Than on the Sai Gon river.

According to SIWRP, the government agency in charge of irrigation planning in southern Vietnam, irrigated area in the basin will increase by more than 500,000 hectares by 2010—at a very high rate of increase of 5.1 percent per year—to reach 1,350,726 hectares. According to the estimates by Sub-NIAPP, the agency in charge of land-use planning in southern Vietnam, the area will increase to approximately 1,329,074 hectares. For projection purposes, in a first approach, the Sub-NIAPP cropping pattern has been included into the model proportionately to the 1999/2000 area. Exceptions were made for specific large-scale projects, like Phuoc Hoa irrigation area (6,300 ha in Binh Duong/Binh Phuoc, 14,400 ha in Tay Ninh, and 31,050 ha in Long An), and the Song Luy project in the Binh Thuan Province. In the next phase, irrigated area by irrigation zone to be finalized by SIWRP will be used. Sub-NIAPP expects an irrigated cotton area of approximately 21,000 hectares by 2010. However, as no survey observations on cotton were available, the crop has so far not been included in the analysis. Sub-NIAPP also projects large increases for irrigated perennial crops: fruit trees, by 59,000 hectares; irrigated coffee, by 36,000 hectares; and pepper, by 29,000 hectares. Paddy areas in the summer-autumn and rainy seasons are also expected to increase by approximately 100,000 hectares, whereas dry-season rice is projected to slightly decline, by 3,300 hectares (see also figure 2). Irrigation fees for surface withdrawals were doubled compared to the baseline, and for groundwater pumping they were increased to US\$0.09/m^3. All other parameters were left unchanged.

Several provinces in the Dong Nai river basin have plans for major water-supply capacity expansion by 2010. For example, HCMC plans to increase its capacity from 930,000 m^3/day in 2000 to 2.2 million m^3/day in 2010. Other provinces with major increases include Tay Ninh from 9,300 m^3/day in 2000 to 28,800 m^3/day in 2010, and Ba Ria Vung Tau from 62,600 m^3/day in 2000 to 171,900 m^3/day in 2010. From data available for several provinces, total expansion is estimated at about 1.5 million m^3/day. However, only a share of capacity will translate into deliveries, and part of these deliveries will be for industrial water supply. For population projections, the growth rates in the basin for domestic and rural areas during 1995–2000 were applied to the 2000–2010 period (see table 11), with an average growth of 3.59 percent per year, largely due to very high urban growth. The projected 2010 basin population reaches 19 million people, 59 percent of whom will live in urban areas, up from 49 percent in 2000. Whereas water demand in 1999 was based on supply capacity, complemented with minimum standards of 40–50 l/cap/day for

Table 11. Urban and rural growth in the DNRB, 1995-2000.

	Urban growth 1995-2000 (%/yr.)	Rural growth
HCMC	4.69	-5.98
Ninh Thuan	3.81	1.50
Binh Phuoc	5.21	5.21
Tay Ninh	5.05	0.95
Binh Duong	17.06	-1.35
Dong Nai	3.18	1.54
Binh Thuan	7.59	0.45
Ba Ria Vung Tau	7.03	0.62
Lam Dong	5.47	3.03
Long An	4.86	0.49
Dak Lak	na	5.77

Note: na = not applicable.
Source: Calculated based on Statistical Yearbook 2000. Statistical publishing house, Hanoi, 2001.

[16]These costs include the irrigation infrastructure for Phuoc Hoa and Song Luy.

districts without public water supply, water demand for 2010 is calculated based on supply standards: 60 l/cap/day for rural areas and 120 l/cap/day for urban areas. Total estimated demand reaches 666 million m^3 up from 336 million m^3 in 1999/2000. Income growth is projected at 5 percent per year and water prices are projected to double over the time frame.

For 2010, total net industrial water demand is estimated at 491 million m^3, at an annual growth rate of 5 percent per year. Industrial water delivery costs increase by 50 percent over the period, averaging US$0.39/$m^3$ by 2010. It is assumed that the share of surface water and groundwater deliveries remains unchanged.

Analysis

For the 2010 scenario, total off-stream water withdrawals are estimated at 4,647 million m^3. Domestic surface withdrawals increase by 89 percent to reach 1,023 million m^3, industrial withdrawals by 72 percent to reach 1,052 million m^3, and irrigation surface withdrawals by 11 percent to reach 2,572 million m^3. Minimum flow requirements to ensure withdrawals at the major domestic supply offtake points increase by 27 percent to reach 4,415 million m^3. Moreover, total groundwater abstractions increase rapidly to 854 million m^3, an increase of 201 percent over baseline pumping. Irrigation pumping increases by 382 percent to reach 496 million m^3; domestic pumping by 104 percent to reach 322 million m^3; and industrial pumping by 50 percent to reach 35 million m^3. Total groundwater abstracted represents only 8.4 percent of estimated total shallow groundwater capacity as yet. However, in the key dry-season months of January to March, an average of 37 percent of capacity is exploited. Moreover, in several provinces, the share is much higher and even reaches 100 percent in January and March in the Binh Phuoc Province, a key grower of perennial crops relying on groundwater (see table 12). Total hydropower produced amounts to 9,541 gigawatt hours, an increase by 81 percent over 1999/2000 production levels.

Figure 14 shows the discharge and demand situation under the 2010 alternative scenario. Discharge during the dry-season months of January to April, in fact, increased by an average of 150 million m^3 or 57 m^3/sec compared to the baseline scenario. The shift of additional flow into the dry season is due to the additional storage of 2,901 million m^3 to be constructed by 2010. However, although the 2010 scenario envisions large-scale investment into additional reservoir storage, the

Table 12. Share of shallow groundwater exploited, 2010 scenario (in %).

	January	February	March
Binh Duong	48	57	49
Binh Phuoc	100	98	100
BRVT	34	36	84
Dong Nai	22	36	32
HCMC	37	40	36
Long An	42	53	59
Lam Dong	33	67	10

gap between the demand and supply curves is reduced to half the baseline level for the month of February, and the basin is moving into a semi-closed state. Moreover, under the 2010 scenario, demands would not be met from natural flows (no storage) during three consecutive months (February–April, by between 214 million m^3 and 406 million m^3).

A significant result of this preliminary 2010 scenario is that the projected cropping area of 1,307,774 hectares cannot be achieved. Instead, the area is reduced by 139,129 hectares or 11 percent (see table 13). The major decline in percentage terms occurs for sugarcane, followed by rice and, in absolute terms, for rice, followed by coffee. If the complete projected cropping area had been implemented, total surface withdrawals could have increased by a further 1.8 BCM, an increase of 72 percent. However, most of this would be demanded in the summer-autumn and rainy seasons. Local water shortages in selected areas during the dry season, and particularly the doubling of the irrigation fees for surface areas and the increase of groundwater pumping costs from US$0.07/$m^3$ to US$0.09/$m^3$, compared to the baseline parameters, are the lead causes for the underachievement in irrigation area, making several commodities unprofitable for farmers.

Figure 14. Flows and withdrawals, 2010 scenario.

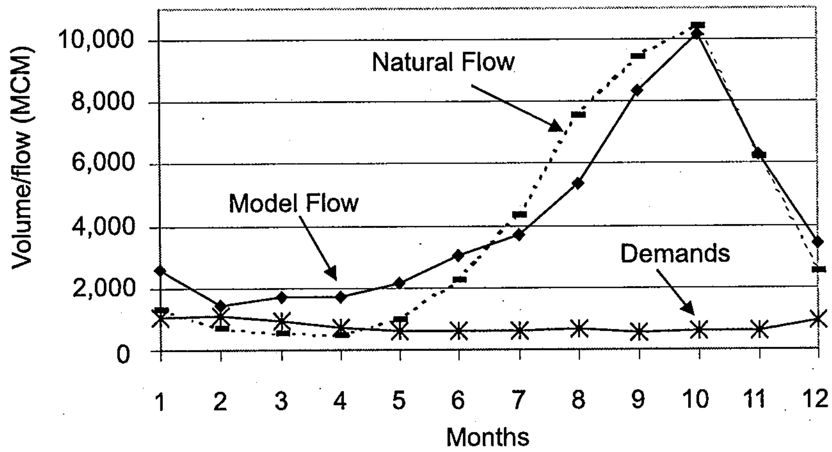


Table 13. Irrigated area, projected 2010 and change in 2010 scenario result.

	Area, projected 2010 (ha)	Change in area, model (ha)	Change (%)
Bean	26,270	4,378	17
Coffee	201,136	-11,157	-6
Fruit trees	103,809	13,084	13
Maize	35,749	7,101	20
Paddy	670,620	-198,866	-30
Peanut	86,338	16,616	19
Pepper	39,465	7,893	20
Sugarcane	13,350	-4,385	-33
Tobacco	17,161	3,432	20
Vegetables	113,876	22,775	20
Total	1,307,774	-139,129	-11

Table 14 shows the net profit situation in 2010, compared with the baseline result. Total basin profits increase by 50 percent. Irrigation profits increase steeply, by a factor of 2.7; profits from water use in industry jump by 53 percent and for hydropower by 66 percent. Domestic net benefits, on the other hand, decline, despite a large increase in the withdrawal capacity. This is due to the doubling of supply costs incorporated for domestic uses. Thus, by 2010,

Table 14. Profits and withdrawals, 2010 scenario, compared with baseline.

	2010	1999/2000	Change
Profit/Benefit (M US$)	3,228	2,123	52
Irrigation	886	323	174
Domestic	508	615	-17
Industry	1,576	1,030	53
Hydropower	258	156	66
Irrigated area ('000 ha)	1,169	753	55
Withdrawals (MCM)			
Agricultural water withdrawal	3,068	2,414	27
- pumping	496	103	382
Domestic water withdrawal	1,345	700	92
- pumping	322	158	104
Industrial water withdrawal	1,087	635	71
- pumping	35	23	50

the water demands in the basin can still be met without major competition among water-using sectors and the total benefit for the basin economy is set to increase. However, several issues need to be further studied, including the costs of planned investments, as well as the likelihood of planned investments, for example, in the irrigation sector.

Conclusions

The paper has introduced an economic-hydrologic river-basin model and its application to the Dong Nai river basin in southern Vietnam. The model describes the water-supply situation along the river system and the water demands by the various water-using sectors. Water benefit functions are developed for productive water uses, and minimum in-stream flows are included as constraints. Water supply and demand are then balanced, based on the economic objective of maximizing net benefits to water use. This structure allows for inter-sectoral and multi-province analyses of water allocation and use with the objective of determining trade-offs and complementarities in water usage and strategies for the efficient allocation of water resources.

This type of model can help the provinces in the newly formed Dong Nai Planning Management Council to structure the complex reality of the Dong Nai water-resources system. The model can be used as a planning tool, focusing on the investment side, and even more so as a tool to develop strategies for basin management. The model can support policymakers in their decision-making processes from an economic-efficiency perspective. Water allocation mechanisms need to be efficient, equitable and environmentally sustainable. The model developed for the DNRB inherently ensures efficient water allocation in the basin as water is allocated according to its scarcity value to the highest-valued uses and, once those are satisfied, to other uses, so long as the overall economic profit from water use across the basin increases. At the same time, minimum in-stream flows are guaranteed. However, efficient water allocation is not necessarily congruent with actual water allocation and use in the Dong Nai basin. Thus, baseline profits might be larger than actual profits in the basin, and the behavior simulated in the model under alternative scenarios will likely not be replicated in the same form in the real world.

Based on the preliminary results from the modeling framework, a series of general conclusions can be drawn for the DNRB: trade-offs in water uses between the various water users and uses in the basin do exist; however, at the current stage of agricultural and economic development they are rather small and are largely confined to the dry season or low-flow conditions. The DNRB today can be characterized as an open basin, that is, sufficient water resources are available throughout the year for continued agricultural and economic development. However, as the 2010 scenario shows, the basin does approach a semi-closed state, where demand in the dry season cannot be fully met. Moreover, a trade-off analysis for the baseline year has shown that overall trade-offs in the baseline are relatively low, but that the irrigation sector will be most adversely affected if other sectors are favored in development, due to the relatively lower value of water in agriculture and the large quantities of water involved in irrigated agriculture.

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[17]The projected cost for the North-East South Region is VND 781 billion; an exchange rate of US$1.00 = VND 15,000 has been applied.

The choice of cropping pattern and crop alone could save large amounts of water resources in the dry season, as the irrigation water applied and the water productivity vary substantially by crop. Paddy, for example, in general, has a relatively low productivity of water and is one of the least profitable crops in the basin. If quantity-based water fees or higher fees, in general, were to be introduced in the future, careful analysis will be necessary as, in many basin areas, profits from irrigation can be wiped out even at low water-supply costs. However, withdrawals can be very large if no fees are set. According to current cropping plans for 2010, rice area in the basin is set to continue to increase. If plans to increase the irrigation service fee will also be implemented, continued improvements in the quality of rice products would need to be achieved for farmers to obtain sufficient income from rice production.

Model results favor some shifts away from low-value rice crops and towards more fruit trees, maize, peanut and vegetable crops. Continued liberalization of the agriculture sector, combined with improved access by farmers to information, careful market analysis, and improved post-harvest technologies are all strategies that will eventually help save some of the water currently in low-value uses. However, this strategy can only be applied selectively in certain basin areas to avoid market saturation. Model outcomes also show the large impact that increases in irrigation efficiency can have on water savings in agriculture. However, it needs to be further studied if the projected cost for canal lining for 1995–2002 of US$52[17] million in the basin can be justified by those savings, as water is still relatively abundant in the basin. The simulation of alternative prices for pepper and coffee shows their large impact on the irrigated basin economy over the last few years. Stabilizing and increasing farm-gate prices through improved quality and other measures must be a key goal for Vietnam's agricultural policy, particularly for perennial crops, which cannot quickly adjust to the large price swings experienced in the basin in recent years.

Although no closed groundwater balance could be included into the model due to lack of data, the partial analysis shows that groundwater overdrafting could become a reality in the DNRB in the coming decades. This is largely due to the expansion plans for groundwater-irrigated perennial crops, like coffee, fruit trees and pepper. Canal lining might further contribute to declining availability of shallow groundwater in groundwater-irrigated areas, particularly downstream of the Dau Tieng reservoir. Finally, continued and expanded industrial and domestic reliance on groundwater can lower groundwater tables in local areas. However, further analysis will be needed to obtain a better understanding of the existing capacity, and of interactions among groundwater and surface-water sources, before final conclusions can be drawn.

An alternative 2010 scenario shows that basin-water demands can still be met by 2010, although the gap between supply and demand is increasingly closing. Meeting demands hinges on several issues, particularly the implementation of planned reservoir projects—to increase supply—and also on the actual realization of the large planned increases in irrigation development, which would significantly increase demand.

The provinces, and the large number of water-related agencies involved in basin-water allocation, need to cooperate very closely to achieve the benefits indicated from model results. The optimal utilization of the basin-water resources through allocation of water to the highest-valued uses requires extensive information about the quantity and value of DNRB water over space and time. Although the newly established basin-planning management council cannot attempt to play the role of a "close-to-omniscient" decision maker in the basin with "perfect" knowledge about the basin-water resources—the information and transaction costs would be prohibitive—it should strive to go beyond its likely initial focus on only planning, to achieve close collaboration among the basin provinces and agencies so as to increase overall basin benefits while protecting the vulnerable water resource from pollution, particularly in the lower basin.

The next step for the analysis will be the discussion of final parameters and preliminary results of the baseline, as well as a further check on the planned investments up to 2010 and possibly 2020 together with the policymakers and other stakeholders in the basin. Moreover, the model will be calibrated so that the baseline reflects the actual water-allocation and use-situation during 1999/2000 more accurately (positive modeling). Furthermore, alternative specifications of irrigation service fees will be analyzed, as will the benefits and costs of incorporating some of the additional infrastructure projects in the basin. Based on the final model structure and parameters, institutions based on the separate institutional analysis as well as parameters from the national-level study on taxation and subsidies in agriculture and irrigation will be incorporated into the modeling framework. If time permits, a linkage will be made with the SIWRP VRSAP (Vietnam river system and plains) model to allow for a more in-depth analysis of water-quality implications of model results. Finally, the modeling framework will be further employed to explore the impacts of alternative institutions and water-allocation mechanisms on the basin-water economy.

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Part 3

Synthesis

Five-Country Regional Study on the Development of Effective Water-Management Institutions: A Synthesis of Findings from the Case Studies

Madar Samad[1]

This paper synthesizes the findings from case studies of five river basins in Asian countries, carried out by IWMI in collaboration with national research institutions. The case studies were part of a five-country regional study financed by the Asian Development Bank (ADB) on the development of effective institutions for managing water resources for agriculture in water-scarce river basins. The following river basins were selected for study: Fuyang river basin in the People's Republic of China, Upper Inderagiri (Ombilin) in Indonesia, Upper Pampanga in the Philippines, East Rapti in Nepal, and Deduru Oya in Sri Lanka. In 2001, two basins from Thailand, Mae Klong and Bang Pakong, were included as additional sites.

The overall objective of the study was to improve the management of water resources available for agriculture in river basins where there is growing inter-sectoral competition for water, and associated environmental, socioeconomic and institutional issues arising from such water scarcity.

The specific objectives of the study were:

- To carry out a detailed analysis of existing institutional arrangements for water-resources management in selected river basins, with a view to identifying the extent to which they constrain and facilitate decision making related to agricultural water management, especially in the context of inter-sectoral competition for water.
- To apply and validate a conceptual framework for analyzing the institutional arrangements for water-resources management.
- To develop and initiate the implementation of policies and institutional strengthening programs that will lead to improved management of water available for agriculture.

In addition to these country studies, three supplementary case studies were conducted. Two of these were on river basins from developed countries, Murray-Darling in Australia and Omonogawa in Japan. The main objective of the two case studies on developed-country river basins was to identify key elements of successful water-resources management that may be relevant as lessons for developing countries. The third supplementary case study was the Brantas basin in Indonesia. This case study, conducted in cooperation with the Jasa Tirta Corporation, which manages major hydraulic works in the basin, was to examine how an

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effective institutional framework and a basin organization have been developed and installed to cover multiple uses of water in a large river basin in a developing country.

Methodology. In order to provide a unifying element to the study, a common methodology and a set of research questions were adopted (Samad and Bandaragoda 1999). The key components of the methodology were:

- compiling an inventory of the physical infrastructure related to water resources in the river basin
- water accounting
- analysis of the prevailing socioeconomic conditions in the basin
- assessing the current performance of irrigated agriculture in the basin
- analysis of the existing formal and informal institutional arrangements for managing water resources in the river basin and documenting how different stakeholders are included or excluded in water-resources development and benefit appropriation strategies

Physical Characteristics of the Basins

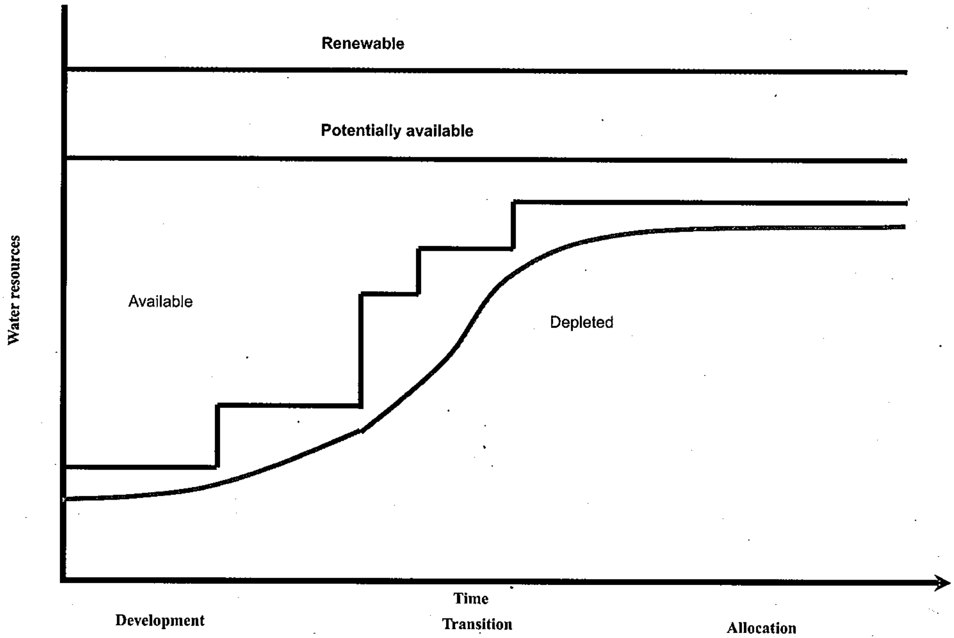
A working hypothesis of the study is that river basins evolve and change over time from both a biophysical and a socioeconomic perspective. Figure 1 illustrates the hypothetical development path of a river basin as defined by Molden et al. (2001). Three distinct stages in the development of water resources in river basins were specified:

- development or construction stage
- transition stage where the emphasis is on managing supplies and water savings
- allocation stage in which the river basin has become "closed" in the sense that all available water has been allocated to various uses

In the *development stage* water tends to be plentiful and low in value. Conflicts are few and the need for coordination among sectors limited. At the other extreme, in the *allocation stage* water is scarce and valuable, with a high potential for conflicts among users. Controlling pollution and water quality is a major problem. A paramount task at this stage is setting priorities for the allocation of water among sectors—irrigation, domestic, industry and environment.

Figure 2 categorizes the five selected river basins in terms of their development stages and highlights salient features. The categorization is based on the results of the water accounting conducted in each basin. The five sites chosen reflect a full range of stages in the development of river-basin water resources. A cross-site comparison of the five basins allows us to develop a perspective on the problems occurring in various stages as a river basin evolves.

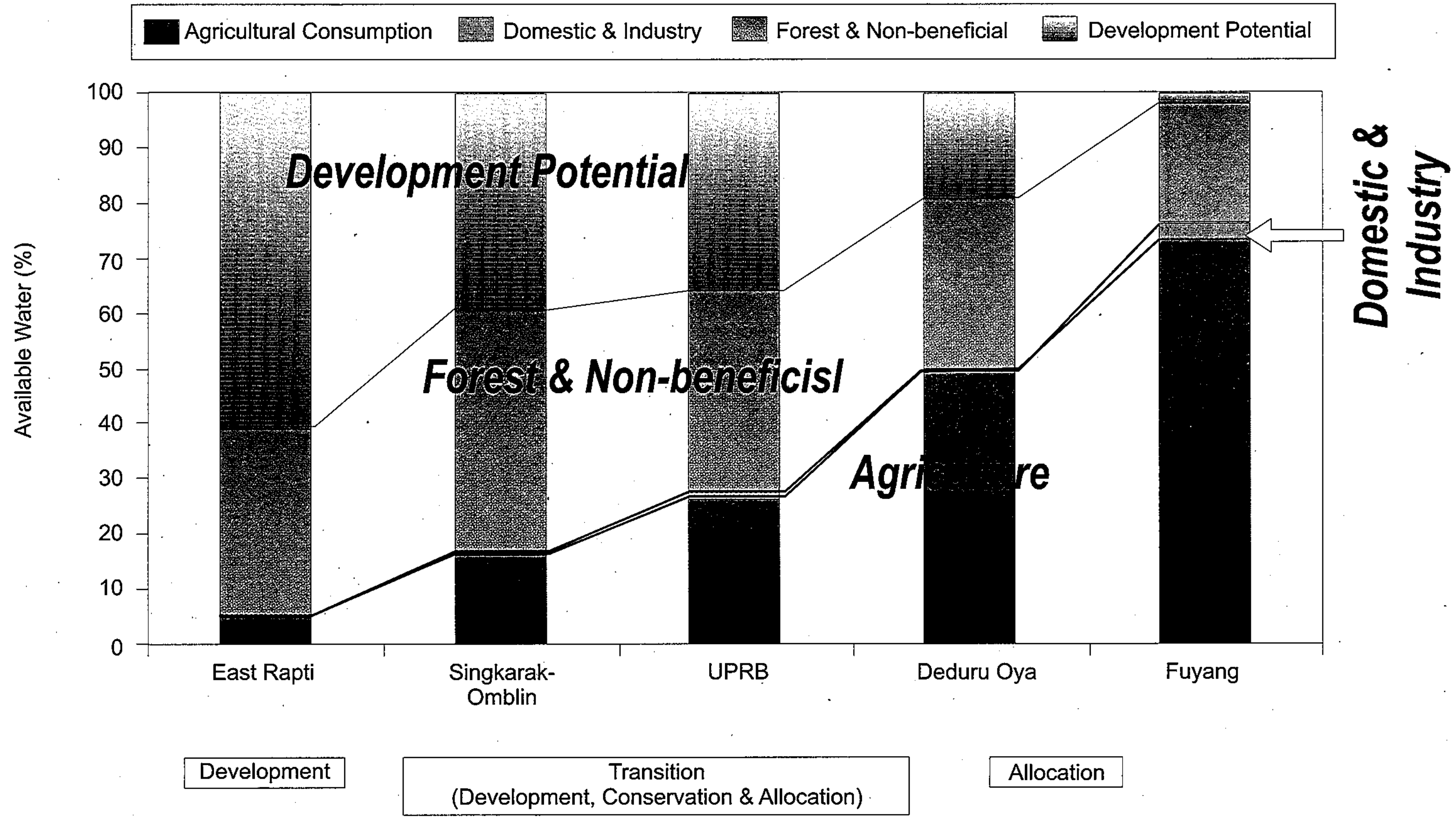
Figure 1. Basin development stages.



The East Rapti river basin in Nepal is an open basin, relatively underdeveloped but well endowed with water resources. Water availability is estimated at about 9,000 m^3 per person per year. In East Rapti there is a very large potential for further development of water resources, but moving from left to right, the potential steadily declines until in Fuyang there is virtually no potential for further development of water resources. With an annual per capita water availability of about 400 m^3, it is one of the most water-short regions in North China. Nonetheless, water demand in this basin for domestic and industrial requirements is quite low. The results suggest that compared to domestic and industrial needs, the requirements for the environment, in particular trees, may be fairly large.

The other three basins fit in-between these two extremes, as indicated in figure 1, and display varying stages of development and levels of water scarcity. The Upper Pampanga basin is relatively well endowed with water, with per capita water availability exceeding 3,500 m^3. The Deduru Oya basin (1,046 m^3/per capita/annum) in Sri Lanka is seasonally water-scarce, especially during the peak of the dry season when there is hardly any river flow. It is also spatially water-scarce, especially in the midstream region of the basin that is predominantly in the drier region of the basin. The Ombilin subbasin located in the upper reaches of the Inderagiri river basin in West Sumatra, Indonesia is an "open basin." But, while there is inter-sectoral competition for water, there are also water-related conflicts.

Figure 2. Development stages of the five basins and sectoral water use.



Socioeconomic Characteristics

Table 1 gives the salient demographic features of the basins. The populations in all five basins are concentrated in rural areas. The Fuyang river basin is the most densely populated and East Rapti the least. In the Deduru Oya basin, there is a heavier concentration of population in the head and tail-end areas, which are more urbanized than the middle region of the basin. High population growth has been reported in East Rapti and Upper Pampanga, 2.7 and 2.9 percent, respectively, per annum in the two districts in East Rapti (Ghimire et al. 2000) and 2.9 percent per annum in Upper Pampanga (Orden et al. 2000). (Comparable data on population growth rates for the Fuyang basin and Ombilin are not available). In Deduru Oya, there is an overall decline in the population growth rates but there is evidence of an increase in population in the more urbanized areas, suggesting an increase in rural-urban migration. Population growth, especially growth in the urban population, will result in an increase in the demand for water supply for domestic purposes.

In all locations, statistics on employment specific to the basin are not available. However employment data from the various administrative areas that fall within the basin indicates that overall, agriculture is the major source of employment of the inhabitants of the respective basins. The proportion of the population dependent on agriculture varies from 40 percent in Deduru Oya to 79 percent in East Rapti.

Incidence of Poverty

The lowest incidence of poverty is in the Fuyang basin with only 6 percent of the population living below the official poverty line. In three other locations, the incidence of poverty is high: Pampanga, 39 percent; East Rapti, 42 percent; and Deduru Oya, 60 percent. Detailed information on poverty is given only in the Sri Lankan and Nepal case studies.

In the Deduru Oya basin, pockets of poverty have been reported from the principal urban center, Kurunegala. The other location where poverty is more pronounced is in the midstream area of the basin where there is acute scarcity of water, especially in the dry season. In the latter case, poverty is attributed to low agricultural-productivity levels due to water scarcity.

In East Rapti, poverty is more pronounced in the rural areas than in the urban centers. Besides locational effects, there are also strong caste and ethnic dimensions to the poverty problem. Certain groups classified as "primitive" and leading a mostly nomadic life are among the worst affected. The incidence of poverty is reportedly high among the ethnically disadvantaged groups, especially among fisherfolk communities. This is primarily due to the decreasing fish population in the river, caused by overfishing and by water-quality problems resulting from the discharge of industrial effluents into the river.

Table 1. Salient socioeconomic features in the selected river basins.

Characteristics	Fuyang (China)	Inderagiri-Ombilin (Indonesia)	Upper Pampanga (Philippines)	East Rapti (Nepal)	Deduru Oya (Sri Lanka)
Total population (millions)	15.6	0.7	1.5	0.6	1.0
Population density (persons/sq. km)	686	396	450	212	378
No. of urban centers	4	4	3	3	22
No. of villages	9,092	400	325	na	2,807
Urban population (%)	28	na	36	25	10
Rural population (%)	72	na	64	75	90
Per capita availability of water (m^3)	868	na	3,630	9,034	1,046
Urban households having piped water (%)	97	na	27	36	21
Rural households having piped water (%)	77	na	na	na	9
% employed in agriculture	67	59	61	79	40
Proportion of population living below national poverty line (%)	6	na	39	42	60

Performance of Irrigated Agriculture

Deduru Oya

A unique feature of the Deduru Oya basin is water scarcity in the midstream region. This area has the highest concentration of small tank systems in the entire basin. Water scarcity has seriously affected irrigated agriculture in the small tank systems. Rice is the main crop cultivated under irrigation in both the wet and the dry seasons. In some of the water-scarce areas, non-rice crops are grown in the dry season.

In recent years, there has been an increase in groundwater abstraction using diesel- and petrol-powered pump sets. These are used primarily for nonagricultural purposes such as brick-making. In some places, water pumps are being extensively used to lift water directly from the river for irrigation. Rice and other field crops are the main crops grown by river lift irrigation in the head and middle regions of the basin. In the tail-end areas vegetable cultivation is the dominant activity.

Farmers identified sedimentation and silting of tank beds, reduction of inflow into the tanks due to blocking of natural watercourses by encroachers, and unplanned development activities in the tank catchments as some of the major hazards in the basin. Unregulated sand mining carried out on a large scale was reported as the major cause of environmental degradation in the Deduru Oya basin. It is the biggest commercial activity in the basin. Excessive sand mining has resulted in seawater intrusion, loss of natural ponds along the river and reductions in the groundwater level, and in disturbing the stability of bridges across the river.

East Rapti

Agriculture is the major source of livelihood of the population in the basin. Of the total economically active population of the Makawanpur district, 83 percent is involved in agriculture, slightly more than the national percentage. In Chitwan, 75 percent of the population is engaged in agriculture. It is estimated that about 26 percent of the total land area in the basin is used for agriculture. Of the total area cultivated, some 18 percent is in the river valleys and inner plains. These are the major irrigated farming areas in the basin. The cropping intensity (CI) of these areas is between 200 and 300 percent. Cropping patterns in such areas with year-round irrigation facilities are:

- Paddy-Fallow-Paddy
- Paddy-Wheat-Paddy
- Paddy-Wheat-Fallow
- Paddy-Legumes-Paddy
- Paddy-Legumes-Fallow

However, in areas with seasonal irrigation facilities, the cropping intensity approaches 200 percent. The cropping patterns in such areas are:

- Paddy-Wheat
- Paddy-Legume
- Paddy-Maize
- Maize-Oilseeds
- Maize-Maize
- Paddy-Vegetables
- Maize-Vegetables.

Livestock (improved breeds of buffaloes and cows) and poultry farming are also very popular in the plains. The hilly areas of the basin are largely rain-fed. The dominant cropping patterns in these hilly areas are:

- Maize-Millet
- Potato-Millet
- Maize-Potato-Fallow
- Maize-Fallow

Nearly 75 percent of the holdings are smaller than 1 hectare each. Landownership in the basin is highly skewed. About 46 percent of the householders own only 16 percent of the total available cultivable land, whereas some 6 percent of the householders own approximately 26 percent of the total cultivable land.

A significant development over the last few years is the proliferation of groundwater development, particularly in the plains. A major reason for the rapid spread of groundwater development is the subsidy amounting to 60 percent of the cost for the establishment of tube wells. More recently, the government has suspended the subsidy program. This has slowed down the establishment of tube wells.

Fuyang Basin

Fuyang is one of the most water-short basins in North China. The availability of per capita water resources is less than 400 m^3. Agriculture is the largest user of water. The share of agricultural water has been declining over time, from 81 percent in 1993 to 75 percent in 1998. This is primarily due to growing domestic demand. Industrial water demand during the same period has increased by only 1 percent.

The total design area under surface irrigation is about 43,000 hectares. The actual irrigated area is substantially less than the designed area. In the 1990s, the actual area irrigated was only 41 percent of the designed irrigated area. Most of the surface irrigation systems are managed by government agencies, though a contract management system was implemented in some periods. With the decline in surface-water supply and increasing demand for water for agriculture and domestic and industrial uses, groundwater exploitation increased rapidly.

Groundwater irrigation investment was mainly financed by the local villages and townships, with varying extents of government-financed subsidies. Prior to the implementation of the household production responsibility system (HRS) initiated in the late 1970s, investment in groundwater was by local government agencies with financial assistance from higher levels of the government. Farmers contributed family labor for constructing groundwater irrigation systems. These systems were under collective ownership. With the implementation of HRS, investment in groundwater was primarily by private individuals.

There is evidence that groundwater tables (both shallow and deep) have fallen by more than 1 m annually in the past two decades. Urbanization, industry and population growth have also led to increasing surface water and groundwater pollution, which have further aggravated the water-scarcity problem in the basin.

The main crops under irrigation include wheat, corn, cotton, rice and some millet, soybean, peanut, and horticultural crops. With the modernization of agriculture since the 1950s, crop yields have increased. Yield of grain crops has doubled. Over the same period, the yield of ginned cotton has increased threefold.

Ombilin River Basin

The main use of water varies among the three major rivers and lakes that constitute the basin. In the Ombilin river, water is used for irrigation, industry, power generation and domestic water supply. Irrigation and domestic water supply are the dominant uses of water in the other two basins.

The development of the Singkarak Hydroelectric Power Plant, which transfers water into another basin, significantly reduced the outflow of water from the Singkarak lake to the Ombilin river. The reduced water flow in the Ombilin river has adversely affected farmers who rely on the river for irrigation water. Pump irrigation has been adopted by a very limited number of farmers in the last decade.

Marked seasonal fluctuations in the river flow are a major feature of the Ombilin river. For the owners and operators of waterwheels, fluctuations in the water discharge of the Ombilin river have caused several problems in system operation and maintenance (O&M). The inadequate and unreliable supply of irrigation water has adversely affected agricultural production in the basin. Rice yield has declined from an average of 4.2 tons per hectare earlier to 3.1 tons per hectare in 1999. Water quality is an emerging problem. This is mainly due to the discharge of effluent from a coal plant. Fish populations in the river has declined due to the deterioration of water quality. This has affected cash incomes of householders dependent on fishing for their livelihood.

Some Institutional Arrangements in the Selected Basins

Management of Water Resources

In all five countries where the case studies were conducted, there is an explicit recognition of the importance of considering the river basin as the unit for developing and managing water resources. Yet none of the river basins studied were managed by a formal river-basin organization. The management of water resources in the basins was purely on sectoral lines by a multiplicity of government agencies with little interagency coordination.

In China, four major laws and some 30 state regulations provide the institutional framework for managing the country's water resources. The current laws and regulations concern water management, finance, water pricing, water withdrawal permit system, water saving and irrigation district management. Steps are being taken to formulate legislation to strengthen integrated watershed management, water allocation and efficiency issues within and across major river basins (Center for Chinese Agricultural Policy 2000).

In principle, water allocation in the Fuyang river basin should be done by the Hebei Province Water Resources Bureau in coordination with five prefectures within the basin. In practice, the bureau has very limited power in allocating water among prefectures and counties in the basin.

In West Sumatra, Indonesia, where water management is fragmented between several government agencies, a provincial water management committee (PTPA) was set up to coordinate the activities of the various agencies. Basin-level committees are also supposed to be set up. However, up until now no such committee has been formed in any of the six river basins located in the West Sumatra Province.

In the Upper Pampanga basin, several government agencies are tasked with the administration of water in the basin. Their interests and functions are administrative and regulatory in nature. Despite the presence of these agencies within the basin, it is still beset with problems and issues such as siltation of waterways, land conversion, water pollution and lack of a coordinating body to promote effective water-resources management in the basin. The situation is the same in Deduru Oya, where some 20 sectoral departments and agencies are involved with the administration and management of water-resources. East Rapti is no exception, with a multiplicity of agencies involved in water management. There have been recent attempts to make district- and village-development councils responsible for coordinating activities at the local level. They have not been very effective, partly because such functions were considered to be the responsibility of central line agencies and partly due to limited local capabilities.

In all basins, attempts have been made to foster greater farmer participation in O&M of irrigation systems. China has introduced far-reaching institutional reforms in the groundwater sector with decollectivization of the groundwater systems and transferring them to private ownership and management. The management of surface irrigation systems has been vested with the local government authorities. In the other locations, lift irrigation systems, both river lift and groundwater systems, are managed by individual owners, except in Nepal where the larger systems are managed by water user associations (WUAs). The larger surface irrigation systems are under joint WUA-agency management. In Sri Lanka, however, the minor schemes are managed by farmer organizations.

Water Rights

Deduru Oya. Water rights in the basin come within the purview of national statutes relating to water. The Crown Land Ordinance of 1949 gives a person who occupies the land on the bank of any public lake or stream the right to use water in that lake or stream for domestic use, and livestock or agricultural purposes provided that it is extracted by manual means. The owners of private lands can extract groundwater in their lands without any restrictions. There are no rules or regulations to control their water use. Water rights relating to irrigation are clearer. In old irrigation schemes, such as the small tanks in old villages in Sri Lanka, water rights are defined traditionally. However, the tank, irrigation canal system and the catchment area are entirely government property. In new schemes, the allottees have equal rights over water. Under water-scarcity conditions, the proprietors can take decisions on which part of the irrigation system is entitled to water in a given season, at a cultivation meeting held for that purpose.

East Rapti. In Nepal, the Water Resources Act of 1992 and its bylaws in 1993 vested the ownership of all the water resources in the country with the government. A government license is required for the development of the water resources other than those on the land of a landowner. However, the development of water for individual and collective use for drinking and irrigation does not require a license. Water rights in Nepal are available to people in the following four ways (Kayastha et al. 2001):

- natural right for developing water for a limited purpose
- right acquired through license for developing water resources for a specific purpose
- upper riparian has prior right compared to the lower riparian
- customary use right and prior appropriation right

Fuyang river basin. According to the Water Law of China, there are two kinds of water rights related to surface water and groundwater:

- Collective property rights—if a reservoir or a water body belongs to a rural collective organization, property rights to water stored in these reservoirs and water pockets will also belong to the collective.
- State property—all other water bodies, both surface water and groundwater, belong to the state.

According to the regulations on water-withdrawal permits, users (including individuals and institutions) cannot draw water from any river, lake or groundwater resource without obtaining a water-use license. The water-resources management agencies at each level have the right to issue a license to the water user. At present, water trading or transferring the water withdrawal permit or the water use right is prohibited. In the event of any violations, the water-resources administration or any other relevant authority can revoke the water-withdrawal permit and expropriate unlawful income.

Ombilin. According to the Indonesian constitution, water is a god-granted resource and should be used for the highest level of welfare of the people. Therefore, water is owned communally by all citizens. No individual ownership can be claimed over water. This idea also provides the basis for the state right to control—but not to own—water. This state right to control water is exercised by the government. The legal framework exists to issue licenses granting use rights, but such licenses have not yet been issued for water use in the Ombilin subbasin.

Upper Pampanga. In the Philippines, the utilization of surface water and groundwater is governed by the Philippine Water Code through the National Water Resources Board (NWRB). All the water belongs to the state and is not subject to any acquisitive prescription. The State may allow the use or development of water by administrative concession through the issuance of a water right to a user. The water right is the privilege to appropriate and use water granted by the government through the NWRB. The measure and limit of appropriation of water are beneficial use as well as the utilization of the right amount during the period that the water is needed for producing the benefits. Priorities in appropriation of water follow the priority in time principle, except in times of emergency when the use of water for domestic purposes has a superior right to other uses.

A Comparative Perspective on the Five River Basins

Commonality in the Five Basin Studies

1. Explicit recognition of the importance of IWRM.
2. Explicit recognition of the river basin as the unit of management of water resources.
3. Growing scarcity of water and inter-sectoral competition for water.
4. In some countries, water for domestic use and industry is given priority over allocations for agriculture.
5. The need for a clearer definition of water rights.
6. Groundwater is emerging as an important source of water. Given this trend, groundwater management is becoming an important issue.
7. Water-quality issues and committing water for environmental purposes are major issues.

Major Problems in the Respective Basins and Proposed Solutions

Table 2 provides a checklist of problems as reported in various studies. There are four problems common to all five sites: a) need for reliable data, b) inadequate planning, c) absence of well-defined water rights, and d) absence of mechanisms for integration of the development and use of surface water and groundwater. Other problems tend to vary from site to site although water inadequacy in the dry season is common to all sites. The site-specific problems and proposed solutions are highlighted in the following paragraphs.

Deduru Oya

Problems

- Inadequate surface water and groundwater resources in the middle reaches of the system coupled with high incidence of poverty.

Table 2. List of problems reported in the case studies

Issues	Basin				
	East Rapti Ombilin	Singkarak Pampanga	Upper	Deduru Oya	Fuyang
A. Basin-Level Issues					
Need for reliable data and information management	✓	✓	✓	✓	✓
Inadequacy or absence of basin-level planning procedures	✓	✓	✓	✓	✓
Absence of well-defined water rights and allocation principles	✓	✓	✓	✓	✓
Absence of institutional mechanism to integrate surface water and groundwater resources development and use	✓	✓	✓	✓	✓
Watershed degradation and surface water and groundwater pollution	✓				✓
Absence of river-control measures				✓	
B. Sector-Level Issues					
Water inadequacy during dry season	✓		✓	✓	✓
Head-tail differences			✓	✓	
Groundwater decline					✓
Low productivity	✓			✓	
Inadequate water control			✓	✓	✓
Waterlogging and flooding			✓		

- Unregulated proliferation of wells and pumps lifting water from the river.
- Inadequate river flow at the tail end during the dry season, coupled with industrial development and shrimp farming, causing conflicts and environmental problems: destruction of mangrove swamps, seawater intrusion and groundwater contamination.
- Uncontrolled exploitation of river resources, e.g., sand mining, leading to lowering of the water table.

Solutions

- Creation of a river-basin management committee.
- Coordination of river-basin management and planning at the district, division and agrarian-services levels.

Fuyang

Problems

- With the basin becoming "closed" about 1980, shift to emphasis on groundwater development for agriculture.
- With agricultural reforms beginning in 1980s, shift toward privatization of groundwater.
- Depletion and overdraft of groundwater resources.

Solutions

- Strengthen enforcement of national water policy, laws and regulations.
- Promote market-oriented property rights management and innovation measures: rational water price, water markets and water-rights transfer.
- Implement a permit system for groundwater withdrawal.

East Rapti

Problems

- Adequate water resources but inadequate development of groundwater resources and management of water resources for conjunctive use.
- Need protection of water requirements for the Chitwan National Park and the buffer zone.

Solutions

- Develop a basin-level coordinating facility.
- Support shallow tube-well development to reduce farmers' dependence on river water.

- Review, establish and implement water rights among sectors.
- Strengthen and implement pollution-control standards.

Ombilin

Problems

- Rapid decline in water availability and reliability for agriculture due to the construction of a hydropower plant and the interbasin transfer of water.
- Nonexistance of an organization for river-basin management.
- Formal water use rights not implemented, not only due to gaps in regulations but also due to lack of data on which to make decisions.
- Need for low-cost technology for lift irrigation to replace waterwheels whose performance has been impaired by reduced flows.

Solutions

- Short term—establish water allocation rules and release more water to the basin.
- Short term—improved technology for lifting water.
- Long term—develop a Brantas river-type basin-management body.
- Long term—review and strengthen water laws, rights and regulations.

Upper Pampanga

Problems

- Adequate water, but more storage facilities and water-conservation measures along with conjunctive use of groundwater are needed to reduce temporal and spatial shortages of water in the basin.
- Rapid decline in O&M budgets coupled with government decision on complete irrigation-management transfer.
- Growing deterioration of the quality of surface water due to increased industrial and municipal pollutants.

Solutions

- Form a river-basin coordinating council.
- Strict enforcement of existing laws, regulations and policies on pricing, allocation and water quality.
- Strengthen and enhance irrigation association capacity for O&M.

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[2]This section is based on the report prepared by Makin et al. (2002).

Lessons from Case Studies on Advanced River-Basin Management

Three supplementary case studies of what were considered as advanced river-basin management were carried out with the aim of drawing lessons that might be useful for developing countries. Two of these were river basins from developed countries: Omanogawa basin in Japan, and Murray-Darling basin in Australia. The third was the management of the Brantas basin in Indonesia. The following paragraphs highlight some of the key features in these basins that might be useful inputs for designing management systems for river basins elsewhere.

Omanogawa

Omonogawa is well endowed with water resources.[2] Even in years of severe drought, such as 1994, a considerable volume of water was discharged by the river system. It is an urbanized basin, with an urban population of about 70 percent out of a total population of around 690,000. Agriculture is a secondary activity. The younger generation finds it less attractive as an occupation due to the limited income potential from agriculture compared to industry and the public and commercial sectors. The area under paddy cultivation has been reduced over the past 20 years as the impacts of reduced consumption took effect, as the nation became wealthier and reduced subsidies.

Omonogawa has a long history of over a thousand years of water development and management initiatives that originate from the water users, specifically farmers. In common with many countries, there are many institutions with interests in management of water resources. In Japan, the Ministry of Construction has the predominant role in river-basin development and management, a position that has been maintained for over a hundred years. Although the role of the public sector is central to water-resources management, farmer groups have a well-established role based on participatory development and management of natural resources for the protection of agricultural water resources. In recent times, numerous land improvement district (LID) schemes have been undertaken in the basin. The LID system is recognized as one of the more successful innovations in the region to support user involvement in management of irrigation and water-resources schemes. However, the LID system has grown out of long experience in communal management of land and water resources. This experience has included many years of bitter and painful conflict among farmers concerning water allocation. The prevailing system for water management has been developed gradually by farmers themselves, subsequently formalized by the Land Improvement Act, promulgated in 1949.

Individual LID management organizations are responsible for the daily operation, maintenance, and development of the irrigation and drainage systems. A noteworthy feature is that LIDs reinstated traditional forms of water distribution, originally superceded following construction of the main intake channel. The LIDs are also responsible for the quantitative measurement of water abstractions and also for water-quality measurements. The LIDs can

[3]This section is based on the report prepared by Young and McDonald (2001).

force municipalities or industrial users to construct and operate water-treatment plants if discharges are not within the approved standards.

Key Lessons from the Basin

1. Administration of a water-surplus basin does require positive management—to ensure drainage and flood-control structures are operated and maintained correctly. During times of drought, even in water-surplus basins, there needs to be a well-documented and effective system available to manage revision of water allocations to ensure that basin-scale impacts are minimized.

2. Water-quality issues can be dealt with effectively when the sectors involved are able to monitor and evaluate compliance of the other sectors.

3. Water-management agencies focused on agricultural water management, such as the LIDs in the Omonogawa basin, have a major role to play in the management of water resources. With appropriate delegated authority and support, these agencies can be highly effective.

4. The need to involve water users in making decisions.

5. The need to build on traditional institutional arrangements, which are time-tested and adapted to local conditions and needs.

The Murray Darling

The Murray-Darling river basin was chosen for study as it typifies a basin where the hydrological boundary extends over several administrative regions and the institutional arrangements are in place for effectively coordinating water-management functions in a large geographical area.[3] The basin is managed in a framework that involves the Commonwealth (or Federal) Government, four states, and one territory. The framework involves layers of representative bodies that consist of a Ministerial Council, the Murray Darling Basin Commission, and a series of high-level groups interspersed with community representatives. These layers make up the fora where strategies and policies are set out for sharing the water and managing the serious problems of water quality in the basin.

In Australia, water resources are largely under the jurisdiction of the state and territorial governments. The Federal Government participates in water and water-resources management through other means, such as legislative and executive capacity.

The Murray-Darling river basin is managed by individual states but there are overarching bodies that coordinate many of the efforts of state and territorial governments at the basin level. Rather than amending the Constitution, a Murray-Darling Basin Commission has been formed to manage inter-jurisdictional processes and conflicts in an organized manner. The Commission is the executive arm of the Murray-Darling Basin Ministerial Council that consists

[3]This section is a summary of the report of Sunaryo (2001).

of ministers responsible for land, water and environmental resources in each of the signatory or contracting governments. The Commission is an autonomous organization equally responsible to the governments represented on the Ministerial Council as well as to the council itself. The commission began with a mandate to manage water quantity that has gradually extended to include water-quality issues and, to a limited extent, related land-resources management issues. In the late 1980s, it was given a mandate to initiate, support and evaluate integrated natural resources management across the Murray-Darling basin.

Over the last decade or so, the Murray-Darling Basin Commission has become increasingly aware of the need for, and the benefits of, community consultation. To this end, in 1986 it established a Community Advisory Committee that reports directly to the Murray-Darling Basin Ministerial Council. Today, virtually all commission programs involve a large degree of consultation. Most policy reforms are, at the least, discussed with the council and explored through transparent media and meeting-based processes. Draft policies and strategies are then released and finalized after a period of time.

The lessons from the basin can be summarized largely in terms of how conflicts are managed. Managing resources sustainably has required innovative mechanisms to be put in place that will encourage reform in an environment of cooperative federalism.

The Murray-Darling Agreement is a prime example of institutional rules designed to manage conflicts. The myriad constellations of committees and groups of officials work reasonably well despite the complexity of the arrangements. The key is the continuities created by ministers and their deputies sitting on various committees. Trust between individuals has grown over the years. In these settings, moral suasion works as a mechanism to encourage states to act in a manner consistent with the common good.

Brantas River Basin

The Brantas river basin was selected for a case study as an example of a single organization (Jasa Tirta I Public Corporation) managing multiple uses of water in a large river basin in a developing country.[4] Jasa Tirta Public Corporation was established in 1990 to manage major water resources in the Brantas basin. The corporation also carries out conservation, development and utilization of the river and water sources, including giving information, recommendations, education and guidance. In 1999, the name of Perum Jasa Tirta was changed to Perum Jasa Tirta I.

The guiding principle of the organization is "one river, one plan and one integrated management." One river (basin) is a hydrological unit that covers several administrative areas managed as one unit. There should be one integrated, comprehensive, sustainable and environmentally based concept of a development and management plan. One management system should guarantee an integration of policies, strategies and programs as well as implementation of the system for all of its reaches. The scope of river-basin management covers watershed management, water-quantity management, water-quality management, flood-control management, river-environment management, water-resources infrastructure management, and research and development.

The management system adopted by the organization is based on the application of corporate principles. The organization engages in consultancy services as part of its resource mobilization strategy. Fees collected from water uses are an important source of finance. However, on the basis of political decisions, the agriculture sector—the largest user of water—is exempted from water fees (table 3). Public, private and community participations are

Table 3. The agricultural sector in the five river basins.

Characteristics	Fuyang (China)	Ombilin (Indonesia)	East Rapti (Nepal)	Upper Pampanga (Philippines)	Deduru Oya (Sri Lanka)
No. of surface irrigation schemes	3	184 (river lift)	214	37	3,600
No. of groundwater irrigation schemes	185,527	14	2,445	9	2,453
Surface irrigated area (ha)	150,000	32,180	32,388	98,222	47,150
Groundwater irrigated area (ha)	875,000	—	7,743	25,135	1,515
Main irrigated crops	Wheat, corn, cotton, rape-seed	Rice, mungbean, groundnut	Rice, maize, wheat	Rice, vegetables, corn, onion	Rice, chili vegetables
Annual cropping intensity (%)	155	na	na	156–surface 200–ground water	133-165%-surface 180-300–groundwater
Comparison of current crop yield with yield 10 years ago	Decline in yield of all major crops	No change in yield of major crops	No change in yield of major crops	Drop in rice yield by 14-21%	Current yields of major crops are higher
Reasons for yield change	Water scarcity, institutional constraints	Not relevant	Not relevant	Climatic changes, pest outbreak	Improved agronomy, better prices
Responsibility for O&M—groundwater systems	Individual farmer	—	WUAs	—	Smaller systems–WUAs; larger systems WUAs and Irrigation Agency
Responsibility for O&M—surface-irrigation system	Local government authority	River lift systems (waterwheels) – individual owners	WUAs and Irrigation agency	Irrigation Associations (WUAs) and Irrigation agency	Individual owners
Multiple use of irrigation water	Yes	Yes	Yes	Yes	Yes

considered important aspects of effective water-resources management. Stakeholders are involved at each decision-making level through coordination fora. Roles of the key stakeholders are defined as follows:

- The government, as the owner of the water resources and its infrastructure, plays the role of controlling and regulating at the national and regional level and exercising its public authority.
- The River Basin Management Agency is authorized to manage water resources and infrastructure, including receiving contributions and rendering water-resources services.
- Society acts as users that have the right to receive services and participate in decision making, but is expected to use water efficiently and take part in sustaining the environment.

Key Generic Lessons

- The study has shown that there are clear stages to river-basin development. The development responds to the changing pattern of demand for water over time, linked to population growth and economic development.
- There is a clear need to focus on improved data collection and transformation of these data into useful management information. This information needs to be broadly shared with stakeholders.
- There is an urgent need for clearly defined water rights. Without clear understandings about water rights and effective enforcement, the poor and disadvantaged groups are vulnerable to losing access to water.
- The lessons from the case study of advanced river-basin management (Japan and Australia) suggest that formal "river-basin organizations" are not an essential feature of successfully managed water-scarce river basins. Other arrangements, including various kinds of committees and networks, can often work just as effectively. But there needs to be a clear legal framework, including clarity on water rights, and a regulatory framework to make such arrangements work.
- There is a clear need to design effective mechanisms for stakeholder consultation and enlist their cooperation in implementing programs for developing and managing water resources. Well-designed stakeholder-driven institutions are more likely to have positive outcomes.
- The "success stories," Murray-Darling, Omonogawa and Brantas, suggest that institutional development has been a slow process taking decades. There is a clear need for more research on appropriate institutional arrangements and the sequence in which new arrangements should be introduced.

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Integrated Water-Resources Governance in a River-Basin Context: A Synthesis Paper

Bryan Bruns and D. J. Bandaragoda

Introduction

As water use expands within river basins, the need for coordination among different uses and users grows. Effective institutions for water governance can help prevent and resolve conflicts, while promoting more efficient, equitable and sustainable use of water resources. The studies in this volume report on seven river basins in Asia, pointing out problems and opportunities for improving water governance in the face of current and future demands.

In order to better understand some of the problems and opportunities affecting management of river basins in Asia, the International Water Management Institute (IWMI) conducted research on "Developing Effective Water Management Institutions," supported by the Asian Development Bank through Regional Technical Assistance Grant 5812. The studies examined patterns of water use in selected river basins in six Asian countries. Findings by IWMI researchers and their colleagues highlighted the extent to which management is not yet well integrated, with information scarce and users often unaware of how others are using the same shared water resource. Study activities have helped bring together representatives of various users to begin discussing and formulating ways to address the challenges of integrated water resources management (IWRM) in specific river basins.

The International Food Policy Research Institute (IFPRI) has worked with colleagues in Vietnam and Indonesia to study economic, hydrological and institutional aspects of two basin water-resources systems, also supported by a Regional Technical Assistance grant from the Asian Development Bank (RETA 5866). Based on collection and analysis of information at several levels, simulation models integrated key relationships of water stocks and flows; institutional rules; and economic benefits and costs. The papers in this volume report on the preliminary use of these models to understand current conditions and to assess alternative scenarios concerning future water demand and supply, including the possible consequences of institutional changes in how water is allocated.

These two studies have carried out a series of joint workshops, to share questions, frameworks and findings (for the proceedings of the 2001 workshop, see Bruns et al. 2002). The papers in this volume come from the third workshop, held in Bangkok, Thailand in May 2002. This final paper provides an overview and synthesis of some key ideas concerning the papers and presentations in this volume.

The first section of this paper puts the country cases in the context of basins moving from open conditions of water abundance to closed conditions of limited and scarce supplies. Governance issues were the topic of this workshop, and the second section reviews institutional frameworks for basin governance, mostly in incipient stages in the basins covered in the two studies. As discussed in the third section, understanding the problems and potential for integrated water management benefits from basic accounting information to depict quantities of water available and how they are being used. Changing water demands, policies and institutions have impacts on agriculture and other sectors, and as discussed in the fifth section, integrated hydro-economic modeling provides one way of assessing current conditions and exploring scenarios for changes that might occur in the future. Most basins in Asia are in relatively early stages of developing specialized institutions for basin management, making it useful to consider the challenges, limitations and opportunities involved in developing better institutions for governance of water resources in suitably integrated ways, as outlined in the sixth section. The final section of this paper summarizes some of the key challenges for integrated water resources governance in various basin contexts, findings from the various studies, and agendas for action.

From Open to Closed Basins

Changes in river-basin governance can be seen as a response to development, in a process shifting from open basins with abundant water resources to closed basins with scarce, fully utilized supplies. River-basin development can be broadly categorized into three phases, which have different conditions and needs in terms of IWRM, as shown in figure 1, p.225. During the *development phase,* construction to utilize water is the primary concern. During the *transitional phase,* development continues but better utilization of existing resources, for example, through improving irrigation schedules and reservoir operation rules, becomes a concern and there is a need to consider the interaction between uses in different sectors. During the *allocation phase*, utilization nears or exceeds available supplies, so there are increasing pressures to clarify how water is allocated, adjust for how usage affects water quality for other users and to transfer water among uses.

As seen in earlier chapters in this volume, the cases in IWMI's study on "Developing Effective Water Management Institutions" cover all three phases, from the East Rapti basin in Nepal where relatively little of the available water is used to the Fuyang basin in China where surface sources are heavily exploited and drawdown of groundwater poses a major challenge for management. The Pampanga basin in the Philippines is in the early stages of shifting from a focus on irrigation to greater consideration of how to integrate competing demands from various sectors. While water is still relatively abundant in the Ombilin subbasin in Indonesia, management issues have begun to appear. Construction of a hydropower installation that transfers water into another basin affected downstream farmers who had relied on waterwheels for irrigation. In Sri Lanka's Deduru Oya basin, seasonal scarcity is most pronounced in the middle areas of the basin but water usage is still predominantly agricultural. In the Dong Nai basin in Vietnam, although much water is still available and groundwater is not yet heavily used, there is a need to prevent saline intrusion during low flow periods and to coordinate planned growth in demand and supply. The Brantas basin in Indonesia faces greater demand, and there is a need to integrate power production and agricultural demands with industrial and urban use, particularly during the dry season.

Monsoonal climates create major seasonal differences in water abundance and scarcity, so that most of the basins discussed here shift back and forth from being open in the wet season to a closed condition in the dry season. Water accounting on an annual basis presents a summary picture of how available supplies are used, but seasonal conditions have an important influence on institutional development. The need for management is often driven by seasonal scarcity, lasting for weeks or months during the dry season. Even water-abundant basins, such as East Rapti and Pampanga, face challenges to provide more effective institutional arrangements for coping with competition during periods of low flow, such as protecting supplies for the national park in East Rapti and ensuring urban water supplies from the Pampanga basin. Institutions developed to provide integrated management in early phases of basin development might play a major role in reducing problems and facilitating improved management during subsequent phases of basin development.

Governance Institutions for IWRM

Institutional analysis of basin management should help identify existing and future ways to respond to the challenges of IWRM, which is based on a number of key principles, representing a shift to a more holistic way of thinking about and managing water (GWP-TAC 2000; Calder 2000). Water management should look at all uses, not just those within a single sector, such as irrigation or urban water supply. Attention should be paid not just to water quantity but also to water quality. Environmental impacts and water needs for preserving in-stream flows, wetlands and other aquatic habitats should be taken into consideration. IWRM should deal with the entire basin, not just with a small locality considered in isolation. Management should deal not with surface water alone, but groundwater aquifers and the entire hydrological cycle, including how land use upstream influences runoff, evaporation and infiltration, with subsequent impacts on the timing and amount of water available further downstream.

The implication is that governance arrangements will need to appropriately involve the institutions and organizations that are concerned with all the relevant aspects of water management in a basin. An important conclusion and principle is that every basin is different, there is no single model for basin management that can be applied universally. While it is possible and worthwhile to learn from experience elsewhere, institutional arrangements need to be customized to the conditions of a particular basin.

The conceptual framework for the IWMI studies emphasized three institutional "pillars" of policies, laws and administration (Bandaragoda 2002). Formal and informal institutions constitute "rules of the game," including laws, regulations, organizations, procedures, accountability and incentive mechanisms as well as other norms, traditions, practices and customs. Water-management organizations are nested within a larger institutional environment that encompasses many water-using organizations within and beyond their particular basin.

Institutional analysis in the studies was built on information about socioeconomic, physical and performance indicators in each basin. For the studies, given current trends and likely future conditions, the adequacy and appropriateness of existing institutions were assessed and possible institutional changes identified. The IFPRI studies covered similar information, but emphasized the formulation of quantitative simulation models that could represent key linkages and examine possible changes in infrastructure, operation and institutions. Using the integrated economic-hydrological models, alternative scenarios could be used to explore the implications of changing water allocation in basins, for example increasing costs to users of obtaining water and facilitating transferability of water between uses.

The papers presented in this volume show how governance institutions for IWRM are weak or absent in most of the basins. Sectoral agencies have responsibilities for irrigation, water supply and other matters, but often have little idea of what other users are doing. Coordination among different users may not happen at all, or be done on an ad hoc basis in response to drought or other specific problems.

Rights to use water, and obligations concerning water quality, return flows and other impacts are not well defined. National laws and policies may provide some framework regarding authority and rights in water allocation, but often even those rules are often not worked out in much detail. Fora or platforms to bring together users within and between sectors are not well developed, and those that exist usually lack the capacity to move from discussion to establishment of binding commitments. Institutions to monitor and enforce rules about water use are generally not present, and those that are present often have little or no ability to actually implement whatever legal authority they may hold. As emphasized by the title of the workshop, the need in most basins is not just one of minor technical changes in operational rules, or strengthening implementation and enforcement, but of constituting new institutions through which water can be effectively governed.

This does not necessarily mean that a single, monolithic river-basin organization is the only or best way to manage the basin. As stated in the summary of the five-country studies:

> The lessons from the case study of advanced river-basin management (Japan and Australia) suggests that formal "river-basin organizations" are not an essential feature of successfully managed water-scarce river basins. Other arrangements, including various kinds of committees and networks, can often work just as effectively. But there needs to be a clear legal framework, including clarity on water rights, and a regulatory framework to make such arrangements work (Samad 2003, this volume).

Water Accounting

Water accounting (Molden et al. 2001) provides an important tool to obtain an overview and summary of how much water is available and how it is being used. In the context of phases of basin development, it provides a quantitative picture of how available supplies are currently being used in different sectors. Water accounting results help decision makers involved in water governance to better understand the situations they face.

The IWMI studies show how water accounting can provide a useful framework for integrating information about usage in different sectors. It helps identify the extent of use by different stakeholders, who should be involved in efforts to improve the governance of water within a basin. Trying to systematically account for water helps ensure that issues such as return flows, environmental water allocations, interbasin transfers and groundwater withdrawals are brought into the picture, rather than starting from a narrow sectoral perspective on a single type of water use.

The studies also identified data gaps and needs. Information on water usage is often incomplete, and better data are an important priority for strengthening future management efforts. Socioeconomic data are usually available in the context of administrative units, such as provinces and districts, making it a challenge to provide a good picture of conditions in a river basin. Water accounting on an annual basis provides a useful overview, but many of the challenges for management stem from shortages that are season- and location-specific.

Modeling

Changes in basin governance are intended to result in changes in how water is used. Integrated economic-hydrological models can provide a useful tool for assessing what might be the impact of such changes, comparing alternatives without requiring years of experimentation (Rosegrant et al. 2000; Rodgers 2002). Sets of equations provide a way to simulate the systematic relationships that structure the impact of changes in basin institutions. Chapters 9 and 10 in this volume report on efforts that integrate hydrological modeling of stocks and flows of water within basins with economic modeling of the benefits and costs of farming, hydropower, domestic water supply and other water uses.

Integrated models can help identify the likely impacts of changes, including trends in water use, storage construction, expansion in water services and changes in the costs paid by users to obtain water. In addition to examining the possible impacts of new construction and reallocation of water through administrative or market processes, such models can also look at how users might respond to increased charges for water, changes in the prices of food and agricultural inputs, and other policy changes that may affect water-resources management. As basins close, and developing new supplies becomes more and more expensive, institutional changes need to play an increasingly important role in IWRM. Integrated modeling provides a useful tool for understanding what might be accomplished through institutional changes intended to increase the benefits of water use.

As in most other basins discussed in the workshop, the Dong Nai and Brantas basins still have an overall surplus of water, but are increasingly affected by seasonal shortages. In the short term the Dong Nai faces few constraints beyond continuing to prevent saline intrusion during the periods of lowest flow. However, the models offer a way to project the basin-level impact of planned and proposed projects to increase storage and expand water supply for irrigation, industry and other uses. They can thus integrate the impact of multiple changes in different parts of the basin, together with possible changes in food policies, water charges and other factors. Integrated hydro-economic models can be further developed, for example to examine in more detail the interactions between surface water and groundwater.

IWRM in Basin Contexts

Integrated governance of water resources requires institutions that link users in different sectors, such as farming, industry and urban water supply, who have often known little about who else was sharing the use of the same water resource. Problems of water shortage, flooding and pollution often cannot be solved within a small locality, but require institutions that cover an entire basin or subbasin, from upstream catchments to the downstream delta. Fisheries and aquatic habitats cannot be sustained unless adequate flows and water quality can be assured.

Existing organizations and institutional arrangements often lack the scope, authority, legitimacy and other characteristics needed to be effective in governing how water will be used. Finding solutions is often not just a matter of adjusting specific operational rules or strengthening their implementation and enforcement, but requires changes in governance. There is a need to convene stakeholders and constitute new institutional arrangements, whether by modifying existing institutions or establishing new ones. This makes it important to look broadly and in an integrated way at the governance of water in river basins, at the set of institutions that determine who obtains water, how disputes are resolved and otherwise assist diverse and dispersed water users to coordinate their actions.

IWRM embodies current thinking about the importance of understanding the interaction between water use in different sectors, including the environment. Basins are seen as the natural and relevant units for management efforts. The principle of having better institutions to manage basin water resources is generally accepted. However, ideas are often less clear and more diverse about how to put such principles into practice. River-basin organizations are discussed, but pose questions, including implications for those organizations already involved in activities related to basin water-resources management, the division of responsibilities for policy guidance, planning, regulation and more routine operational tasks, and the roles of stakeholders in decision making (see for example Hofwegen 2001 and other papers in Abernethy 2001). Since groundwater is less visible, and harder to monitor and understand, management of groundwater basins poses even greater challenges.

The studies included in this volume show the feasibility of convening stakeholders to identify and discuss problems in basin management. Consensus was formed about the need, in principle, for IWRM. Immediate agendas usually concerned the need for better information, for education to improve awareness and understanding of basin-management conditions and opportunities, and for further discussion. However, major challenges appear to exist in terms of getting powerful players to "buy in" to a process of joint decisions and compliance with basin and national policies. Resources are limited and changes that seem advisable and necessary may lack political support and funding, unless or until reforms are precipitated by a crisis.

Nevertheless, the agendas formulated during the studies include not just improving information and institutions but also more specific topics, particularly concerning the planning of future construction, and clarifying the allocation of water to different users. The studies have helped analyze and highlight specific management problems that institutions for basin governance will need to be able to manage. Thus future institutional development can be customized to the particular context of the individual basin.

Adapting changes in governance and management to the conditions in each basin could help avoid some of the pitfalls facing attempts to import basin-management concepts in an oversimplified manner (Shah et al. 2001). Rather than replicating models evolved for very different conditions, development can be made more appropriate through better prioritization of what kind of institutional changes are needed, focusing institutional strengthening on specific capacities that will yield useful benefits, and respect for the linkages between land and water use in rain-fed areas upstream with irrigators and others taking water from rivers downstream.

There is also the danger that IWRM might repeat the fate of earlier integrated rural development projects, where good intentions and potential synergies were overwhelmed by the complexities of coordinating diverse activities and agencies dealing with multiple problems requiring very different sorts of capabilities. IWRM may risk similar disappointments, unless institutional development is efficient, well sequenced, and yields some clear benefits quickly. By focusing on priority problems and involving key stakeholders there could be a better opportunity to develop basin-governance institutions that are effectively adapted to local conditions and priorities.

Developing Effective Institutions for Integrated River-Basin Governance

The papers presented at the workshop depict current conditions and management challenges in a range of basins, from water abundance in Nepal to severe shortages in China. In the basins studied, institutions for basin governance are at best in the incipient stages of development. However, the potential has been demonstrated to convene stakeholders, discuss problems and formulate agendas for improving basin governance and IWRM.

An interdisciplinary range of information is needed to illuminate hydrological, socio-economic and other factors influencing management. Water accounting provides an overview of how much water is available and how it is being used. Integrated hydro-economic optimization models provide a tool for depicting relationships and assessing possible scenarios for future development, including alternative policy options for improving the integration and effectiveness of basin water-resources management.

The studies have helped clarify priorities for further study and action to provide IWRM adapted to the contexts of specific basins. Many water users and water-management organizations lack awareness and understanding of who else is using water and how they are affected by other water use, so education is an early priority. Much additional discussion may be needed to generate consensus on how best to improve basin governance, and on the urgency and potential benefits of institutional changes. In developing institutions for basin governance it will be important to ensure that they have adequate scope, for example to deal with such problems as ensuring water for environmental needs, protecting water quality, and controlling sand mining in rivers. Mechanisms are needed to create commitments that will be enforceable, including support from local governments, industrial users, hydropower operators, and other stakeholders beyond irrigation agencies and water utilities. While various types of river-basin organizations may have important roles, there is no uniform answer, no generic remedy for the management challenges facing most basins. Developing institutions that will be effective needs to draw on processes that focus not just on ad hoc solutions to specific problems but to look more broadly and creatively at how to achieve better basin governance.

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