Integrated Water Resources Management in the Chao Phraya River Basin, Thailand

by

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Abstract

Water resources management is challenging due to water's spatial and temporal variability and its significant role in many interacting biophysical systems. Management is further complicated by the existing institutional framework, which may not have adjusted to current conditions of increasing scarcity. This suggests adopting an integrated management approach that considers the interactions among the biological, physical and socioeconomic systems. The shortcomings of many past water management decisions can be attributed to the lack of an integrated approach. Although implementation of integrated management has not been extensive, there is a growing consensus that it is needed to respond to many water resources problems. These problems have been growing more severe and complex due to increasing pressures on resources from population growth and economic development.

The application of integrated water resources management in the Chao Phraya River Basin of Thailand is examined. Thailand has one of the world's fastest growing economies and, as a result, rapidly growing water conflicts. The Chao Phraya River Basin is the site of most of these conflicts. It contains both the country's extensive irrigated agricultural areas and Bangkok, a soon-to-be mega-city. A detailed description of the major water and related resource issues and of the current institutional framework is provided. These descriptions make clear the extensive connections among the different issues and the relative lack of connections among the corresponding institutions. A more integrated management approach would allow more effective use of scarce water resources.

Based on a preliminary application of integrated analysis, general recommendations to improve water resources management in Thailand are given. First, institutional reform and improved water planning on a national, river basin and regional level are needed. Second, the tools of demand management, particularly water service pricing, should be used more extensively. Third, land and forest management must also be considered due to their significant effect on water resources. Finally, human resources development is the key to future success in managing water resources effectively.

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This thesis is dedicated to Sandy, my wonderful wife-to-be. Thanks for being there for me and putting up with it all. Sorry you'll have to do it all over again.

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1. Introduction

1.1 Water As a Resource

Water is a natural resource which is essential to both human activities and the functioning of ecosystems. Although it drops freely from the skies, clean water is tremendously valuable and becoming more so, as its scarcity increases due to population pressures and economic and social development. Society has expended a great deal of effort trying to control the hydrologic cycle and other aspects of the natural environment for human purposes, but many water and other resource problems remain. Millions of people still die from water-related disease and many rivers, lakes and groundwater aquifers are contaminated (Gleick, 1993, p. 3). In both poor and rich countries, water is essential to development and at the same time often degraded by development.

1.2 Need for Improved Water Management

Particularly in developing countries (such as Thailand), effective management of water is essential for sustainable economic growth. The demand for water is increasing as population grows and economic development, urbanization and industrialization increase. In the past, the main focus of water resource managers was to increase supplies of water to keep up with rising demand. Now, however, the economic and environmental costs of new supplies of water are much higher than they were for existing supplies. In addition, as the use of water becomes more intensive, the interactions among different uses and other resources become more significant. In order to effectively deal with this situation, improvements in water management are needed.

These improvements involve the use of a more integrated framework for the analysis of water resource issues. This framework recognizes the importance water plays in many aspects of biophysical, economic and social systems, being careful to pay attention to the interactions of water and other resource uses within and among these systems. The type of analysis resulting from this framework is necessarily very location-specific and the most appropriate geographical unit of analysis is the river basin or watershed. The institutional framework relating to water resources, which is rarely organized around the river basis, is an important aspect of the analysis.

This need for more integration has been recognized recently by major international organizations, such as the World Bank and the United Nations, and many governments. The acceptance of this need has been mostly on a theoretical level; implementation has been fairly limited. There are two general principles to the integrated approach: one top-down and one bottom-up. The first principle involves the extensive use of integrated planning, which considers all relevant socioeconomic, physical and environmental factors. The second involves the use of decentralized implementation involving all stakeholders and using appropriate economic incentives. Both require an appropriate institutional structure to be effective.

1.3 Case Study of Chao Phraya River Basin

This thesis examines the approach of integrated water resources management and analyzes how it could be beneficially applied in the Chao Phraya River basin in Thailand. It will first summarize on a theoretical level what the integrated management approach involves, and then use the Chao Phraya River as a case study to investigate the application of the approach. This analysis will answer the following questions: Could integrated water resources management be beneficially applied in Thailand? What would be required in order to apply this approach? What are the major benefits and difficulties of applying the approach likely to be? In the process of answering these questions, a number of recommendations for improving water resources management in Thailand are developed.

The thesis is divided into seven chapters. Following this introduction, Chapter 2 examines the challenges of managing water resources and describes past management approaches. The chapter concludes with a summary of the major principles of more recent integrated approaches. General background on Thailand and the Chao Phraya River Basin is provided by Chapter 3, while a detailed description of the water resources issues in the Chao Phraya Basin is given in Chapter 4. Once the water resources issues are laid out, it becomes clear that an integrated management approach is appropriate. Chapter 5 examines the current institutional framework. Chapter 6 attempts to apply the principles of integrated management to the issues identified in Chapter 4 in light of the institutional framework described by Chapter 5. Recommendations for institutional reform and shorter-term actions to improve water resources management come out of this analysis. A short conclusion is given in Chapter 7.

2. Integrated Water Resources Management

2.1 Challenges of Water Management

Water is highly variable is space and time which poses a formidable challenge to water resource management. In addition, water plays an integral role in many complex and interacting economic, biophysical and social systems, many of which are not well understood. The following sections examine how water's role in these systems gives rise to many of the major challenges of water resources management. An appreciation of these challenges shows how an integrated management approach which takes into account water's many roles is appropriate in times of increasing water scarcity.

2.1.1 Economic Issues

In most countries, the government has assumed some authority over the management of water resources. This is appropriate because water is critical to survival and the market cannot be wholly relied on to guide water resource investments and uses. Economic theory explains these market failures in water management as resulting from the economic characteristics of water resources (World Bank, 1993, p. 28). Examining these characteristics can provide insight into some of the challenges of water management and the role of government in meeting those challenges.

Water resource infrastructure tends to require large capital investments which are subject to increasing economies of scale. This may create natural monopolies which will overprice for their services unless regulated by the government. Additionally, private investment in water resource infrastructure may be discouraged, particularly in developing countries, because of long investment time horizons, weak capital markets and political interference. Thus, public investment may be warranted.

The uses of water within a river basin or aquifer are interdependent which can lead to the existence of externalities. This occurs, in general, when the benefits and costs of production and consumption affect entities other than those involved in the transaction. Externalities can be either positive or negative depending on whether they encourage underproduction or overproduction of an activity. For example, extraction of groundwater by one user lowers the water table elevation increasing extraction costs for all users. Since this situation encourages individual users to overproduce groundwater, this is an example of a negative externality. An example of a positive externality is the health benefit to society of connecting individuals to a sewer system.

A related issue is the lack of information available to consumers and producers of water services. There is a great deal of uncertainty regarding the hydrologic cycle and its interaction with other physical and ecological systems. The existence of externalities and lack of information means that (hypothetical) market prices would not lead to efficient outcomes. Some form of government regulation or tax might be required to encourage more efficient use of water resources. It is also possible to eliminate certain externalities by more completely specifying property rights to a resource. Government involvement may not be necessary, however, if the interdependent users agree to cooperate for the common good of the resource.

Some water resource services are public goods which may require government intervention to ensure appropriate levels of investment. Public goods have two main qualities: low subtractability and low excludability. Subtractability means how much one person's use decreases the amount or quality of the good available to others, that is, whether there is significant consumption of the good with use. For example, water lines and navigation channels may serve an additional user with no cost to existing users as long as they are being used below capacity. Therefore, these goods have low subtractability when they are being used below capacity and higher subtractability as their use approaches capacity. Low excludability refers to the ability to prevent someone from using the good. The benefits of flood control provided by a dam, for example, are enjoyed by everyone downstream of the dam; there is no practical way to prevent someone from receiving this benefit.

These two characteristics of subtractability and excludability can be used to classify goods and services into four categories: *public goods* (low subtractability and excludability) such as flood control, *private goods* (high subtractability and excludability) such as bottled water, *toll goods* (low subtractability and high excludability) such as sewerage systems, and *open access goods* (high subtractability and low excludability) such as groundwater aquifers. Private entities will not provide goods with low excludability because it is difficult to get consumers to pay. Governments, therefore, may have to provide these goods and finance them though some form of general taxes. In addition, low excludability may lead to overuse of a resource such as a groundwater aquifer, which might require government intervention. The existence of low subtractability will also lead to market failure because levels of investment will be less than optimal, so government subsidy or investment may be required.

The previous analysis showed how the existence of numerous sources of market failure define an significant role for government or other form of collective action in the management of water resources. The market, however, can still play a substantial role. In examining the potential roles of government versus the market, it is useful to distinguish between the provision and the production of infrastructure (World Bank, 1993, p. 85). The provision of infrastructure involves the actions that enable the infrastructure facilities or services to be made available. The production of infrastructure is the act of constructing the facilities or providing the services. Provision and production do not have to be done by the same entity. For example, the provision of a large dam could be undertaken by the government through the collection of tax revenues to pay for it, while the production (i.e., construction) of the dam could be done by a private contractor after a competitive bidding process.

In general, for public goods such as the construction of large water networks or other large infrastructure projects, the government will have to be involved in the provision of the good. However, the production of the good, which includes the construction and operation of facilities, may be accomplished more efficiently by private entities or users groups. This is because private entities have an economic incentive to operate efficiently and users groups have an incentive to operate efficiently for their own benefit. The government still must provide the institutional framework for private entities to operate in, however. Additional efficiencies could be realized if the government was able to eliminate externalities through the use of taxes, subsidies or regulation.

The economic characteristics of water and water services lead to many possibilities for market failure and consequently define a significant role for government in water management. Market forces can be harnessed, however, through appropriate government policies and institutions. The development of these policies and institutions is not a simple task and must take into account more than economic factors to be effective.

2.1.2 Biophysical Issues

The management of water resources must also consider the role of water in physical and biological systems. The most obvious of these is the hydrologic cycle, which determines how much, where and when water is available. When studying these biophysical systems, a logical unit of analysis is the river basin or watershed because its boundaries approximately define a closed system. The flow of water in the river basin is, of course, modified by human activities. Some of these activities, such as dams and diversions, are designed with hydrologic modifications as their major purpose. Others, however, have important impacts on the hydrologic cycle which are more indirect.

Many of these indirect impacts involve changes to the landscape or changes in land-use. Deforestation is a frequent landscape modification which has major hydrologic impacts. The loss of forest cover increases soil erosion and runoff, and so may lead to dam siltation or increased flood severity. This is particularly a problem in tropical regions, where the deforestation causes reduced flows in the dry season and increased flows or floods in the wet season. A related land-use change is the conversion of land to agriculture. Agricultural developments on steep slopes in the tropics without proper soil conservation measures or uncontrolled grazing lead to high soil losses with hydrologic consequences similar to those of deforestation. The runoff from agricultural lands, which often contains pesticides and fertilizers, has a major impact on water quality.

Although considerable progress has been made, there are still gaps in our understanding of these processes which makes it difficult to anticipate the results of many human activities. This is particularly true of the modification of the hydrologic cycle which could result from global climate change. The exact changes are difficult to predict, but they will require a water management system which is flexible enough to respond.

Another factor which should affect water management decisions is irreversibility of many human modifications. Once a water body is contaminated, for example, it is usually very difficult and expensive to clean up. Many rivers and groundwater aquifers in developed countries are contaminated with enormous amounts of resources being spent to remediate them. In the case of groundwater aquifers, complete restoration may not be possible. The prevention of this pollution in the first place would in many cases have been less expensive. Human actions also affect the health of many aquatic ecosystems in many ways. For example, fisheries are an important source of food, but may be destroyed by dams or other modifications. The functioning of ecosystems is affected by most water resource management decisions, but the interactions are very complex and still not well understood in most cases.

Irrigated agriculture supplies much of the world's food. Poor management of land or water resources leads to decreases in agricultural productivity. This loss in productivity can put more pressure on the land and water resources resulting in more loss of productivity. The result is a vicious circle of degradation. Water management must take these interactions into account in order to be effective.

2.1.3 Institutional Issues

The institutional framework relating to water resources is another essential factor to consider as part of effective management. The institutional framework can include "legislation and regulations, policies and guidelines, administrative structures, economic and financial arrangements, political structures and processes, historical and traditional customs and values, and key participants or actors" (Mitchell, p. 6). If responsibility for various aspects of water resources are spread among many different government agencies, then there is a potential for agencies to be working at cross-purposes. This situation is even worse when a river or aquifer in situated in several different countries. Some type of coordinating mechanism must be developed which will be compatible with existing institutions.

The legal system can also have an impact on water resources. In many developing countries there are many poor farmers who are occupying a parcel of land which they do not own, but are using for subsistence agriculture. If the legal system prevents them from obtaining secure title to the land, they are less likely to make investments which will protect the land from erosion or other types of degradation.

The prevalence of market failures and environmental impacts means that effective regulatory systems are required. This is particularly the case if any of the benefits of more decentralized management, such as private or user group production of services, are to be achieved. Since actual water prices are almost always much lower than economic prices, water management institutions have more difficult tasks. As Frederick (1993, p. 62) explains,

> In the absence of prices reflecting resource scarcity, planning that encompasses natural hydrologic regions is necessary to ensure that the opportunity costs associated with alternative water uses are considered. Comprehensive planning should include a strategy for demand management, opportunities for coordinated management of existing facilities to improve safe yields and water quality, and provision of water for public goods.

In order for the planning institution to effectively carry out these responsibilities, it must be well organized and have a skilled staff.

2.2 Past Approaches

Past approaches taken to water resources management in both developing and developed countries have often failed to take into account many of the issues described above. This section provides a few examples of the results of those failures. There has been a movement toward more integrated management, however, which is discussed in the next section.

Governments are often organized so that each type of water use is managed by a separate agency. For example, there might be agencies for water supply, sanitation, environment, transportation and irrigation, and each initiates and runs its own projects completely independently of the other agencies. Often human health and environmental concerns or groundwater and surface water concerns are considered separately. This leads to problems of uncoordinated and fragmented planning and management. If agencies and other stakeholders in a river basin or watershed coordinated their effects at assessment, priority-setting and project implementation, conflicting or duplicative efforts would be eliminated and limited resources would be used more effectively.

Mirroring the organization of administrative institutions, the laws that address water quality issues have tended to focus on particular sources, pollutants or water uses. Although in many countries, substantial improvements have resulted even through this fragmented approach, the cumulative impacts of human activities particularly on ecosystems have not been addressed. It is now understood that the potential causes of water quality degradation are extremely varied. For example, besides discharges from industrial or municipal sources, aquatic systems are threatened by urban, agricultural, or other forms of polluted runoff; land disturbing activities and hydro-modification; altered flows and depleted or contaminated groundwater tables; over-harvesting of fish and other organisms; introduction of exotic species; and deposition or recycling of pollutants between air, land and water (U.S. EPA, 1996).

In the past, most water resource activities were conducted by government agencies with little involvement from the users and other stakeholders of the resource. This has significantly reduced the effectiveness of many government activities because they did not meet the needs of the users. Furthermore, the solutions to many water resource problems depends on voluntary actions on the part of many people, and so cannot be achieved without widespread stakeholder involvement. An example of this is the control of non-point sources of water pollution.

Public authorities in most countries have control over water since it is essential for human survival. In most cases, governments base allocations of water on political or social criteria rather than on economic analysis. This has lead to a prevalence toward underpricing of water, in many cases resulting in inefficient use and allocation. In addition, this makes the financing of water investments more difficult and prevents water agencies from becoming financially autonomous. Underpricing of water occurs in both developed and developing countries. For example, if judged by economic criteria, reallocating water from agricultural areas to the cities of San Francisco and Los Angeles would yield benefits of about $2 billion in 1990-2000 (World Bank, 1993, p. 31). Similar examples can be found in many other countries in all parts of the world.

In general, countries have paid too little attention to water quality and pollution control. A recent review of World Bank water supply and sanitation projects found that of 120 projects 104 included a water supply component and only 58 included a sanitation component (World Bank, 1993, p. 33). In almost all cases, there was inadequate sewer capacity to handle the increase in wastewater due to the water supply project. This will encourage the spread of disease and increase environmental deterioration. Developed countries still have significant water quality problems even though programs to eliminate them have been operating for several decades. In the United States, for example, the most recent survey of water quality by the U.S. Environmental Protection Agency (1995) reported that 36% of the surveyed rivers and streams and 97% of the Great Lakes shoreline were degraded.

In the past, there has been an inadequate analysis of the environmental impacts of public projects. Many projects have adversely impacted water quality and contributed to the degradation of aquatic and terrestrial ecosystems. These impacts were often overlooked due to project-by-project analyses which did not consider the combined impact of interacting projects. The interactions within ecosystems have also frequently been ignored.

Economic growth and development are obviously highly dependent on water and other natural resources. Those natural resources, however, are also dependent on a country's development in at least two major ways (Jalal, 1993). The first is that poverty or lack of development is one of the principle causes of environmental degradation. For example, subsistence farmers may not employ soil conservation measures, better irrigation methods and agricultural extension because they are capital- or knowledge-intensive. The second is that development itself often causes resource degradation. This is because many projects designed to provide economic growth and development do not take into account adverse effects on water and other components of the environment. For economic growth to be achieved most effectively, these interactions must be considered when planning development and water resource projects.

2.3 Trends in Integrated Management

Mitchell (1990, p. 1) described three general levels of integration relevant to water management, which are presented in order of increasing integration. The first level considers the interdependence of the traditional attributes of water, such as surface/groundwater and quantity/quality. Since, for example, surface water and groundwater interact, it would be less efficient to manage them separately. At this level of integration, the focus is on fields such as water supply, wastewater treatment and water quality.

The second level considers how the water system interacts with other systems such as land and the environment. At this level, the focus is on issues such as floodplain management, erosion control, preservation of aquatic habitat, and agricultural drainage. The third and most integrated level considers the interaction between water and social and economic development. This level of integration has been referred to as sustainable development of water resources. Water is a important resource which can be both the basis of and a limit economic development. At this level, issues such as hydropower, water transportation and economic development are considered.

The concept of integrated water resources management is not new. The Tennessee Valley Authority (TVA), perhaps the best known model of integrated land and water management, was established in 1933. The TVA was originally created to provide hydropower, flood control and transportation, but became involved in rural planning, provision of housing, health care, libraries and recreation (Mitchell, 1990, p. 2). Despite being the archetype of an integrated management agency, the TVA has not been replicated in the United States or any other country. Overall, integrated management has not been extensively implemented in the United States (Muckleston, 1990, p. 22). There have been movements in this direction, however, at various times in US history.

The large size and significant hydrologic diversity of the United States combined with the federal system has prevented the emergence of a central water resources management agency. In fact, the power of the federal government has been devolved to the states. As part of this movement, the Water Resources Council and the river basin commissions coordinated under it were eliminated in 1981 (Muckleston, 1990, p. 29). The integrated management functions have been taken over by the states, which have implemented it to varying degrees. Some states, where water is quite scarce, have developed comprehensive state water plans. For example, the *California Water Plan* (California Department of Water Resources, 1994) describes in great detail how the state will meet its water needs through new supplies, demand management and water sector reallocations. For the most part, however, integrated management in the U.S. has been focused on river basin or watershed management.

In the U.S. National Report to the IUGG, Vogel (1995) described a return "to what was once called integrated or unified river basin management" as an emerging theme in U.S. water policy and management. The U.S. Environmental Protection Agency, for example, encourages the "watershed approach" to water quality management. This approach seeks to integrate all water management activities into a coherent integrated framework based around watersheds. In addition, the number of private organizations whose purpose is the protection of river basins or watersheds has been growing.

River basin organizations have been implemented in many countries. In France, water resources are managed by six river basin committees and six river basin financial agencies, whose territories closely correspond to the main river basins (World Bank, 1993, p. 46). For the past twenty-five years they have performed planning and micromanagement functions. The river basin committees are composed of 60 to 110 persons representing interested parties who provide coordination among all the entities involved in managing the river basin. They are the center of negotiations and policy-making at the river basin level. The financial agencies implement the policies set by the committees as well as proposing long-term water development plans, a five-year plan and the level of water fees. They are also responsible for collecting fees, providing grants and loans, collecting data and conducting research programs.

Recent effects have also focused on river basins which encompass more than one country. For example, the International Conference on Integrated Water Resources Management was held in Amsterdam in 1994. The papers given at the conference were largely focused on the integrated management of Europe's river basins (Hosper, 1995).

Many of the efforts towards integrated water management described in the previous section can be classified under the first and second levels of integration as described by Mitchell (1990). There has been very little analysis which addresses the relationship between water resources management and a country's level of development. As described by Rogers, Hurst and Harshadeep (1993, p. 1895), "this lack of analysis is of great concern in many countries, such as Brazil, where as much as 30% of public investment is in the water sector. There is no direct way of showing the strategic consequences of such large allocations in one sector." For other resource sectors, particularly energy, there are well-developed models and methodologies which relate resource planning and management to the economy as a whole.

This level of integration goes beyond what could be performed through management based on river basins. There must be some national agency which could perform this level of analysis. Many countries do not have a institution to do this—the United States is a prime example. Although this lack has not resulted in a water crisis in the U.S., there would be significant benefits from a high-level integrated viewpoint. Rogers in *America's Water* (1993) has called for the creation of a Presidential Water Council which would be responsible for making policy recommendations. For developing countries, the need for higher-level integrated analysis is perhaps even greater because of the need to carefully prioritize the investment of limited resources.

Integrated management has been advocated by major international organizations. The World Bank, for example, in a recent policy paper (1993, p. 40), calls for a "comprehensive approach" that takes into account the interdependencies among sectors (e.g., irrigation, water supply, hydropower, etc.) and ecosystems. This approach is similar to one called "integrated water resources development and management" discussed at the International Conference on Water and the Environment held in Dublin in 1992. The outcome of this conference was a set of recommendations called the Dublin Statement. The first of these recommendations states: "Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer" (Young, 1994, p. 44).

2.4 Summary

The preceding sections has described some of the challenges of water resources management and the responses to these challenges by different countries. There has been a growing recognition of the benefits of a more integrated approach which takes into account the interactions between different aspects of water, between water, land and other resources, and between water resources and social and economic development. This section summarizes the concepts of integrated water resources management and attempts to construct a coherent analytical framework which will be applied in the following case study.

As envisaged by the World Bank (1993), integrated water resources management involves two main principles. First, a framework based on an integrated approach is established which guides water management policies and activities. This framework would be established by the government and includes: defining and implementing a national strategy for managing water resources; providing an appropriate legal, regulatory and administrative framework; guiding water allocation among sectors; and developing water resources in the public domain. Second, efficiency in water management would be improved through the greater use of economic incentives and decentralization including user participation, privatization and financial autonomy in water service production.

The national strategy for water resources would reflect social, economic and environmental objectives and be based on an assessment of the country's water resources. The assessment would include a forecast for water demand that considers population growth and economic development, possibilities for improved management of demand and supply, and existing and potential private investments. The existing levels of water services would be summarized and priorities for service expansion would be laid out. The strategy would also establish policies for water rights, water pricing, public investment and the role of the private sector. The strategy would encourage the use of a river basin or watershed as a unit of analysis. Finally, the strategy would define information requirements for water resources planning and describe how these requirements would be met.

The institutional framework should be designed to facilitate rational management of water resources. Water rights should be clearly defined and a legal basis for water user associations should be established. Procedures which allow the reallocation of water between sectors should exist. Organizational structures, such as river basin organizations, would be needed to ensure coordination of investments, regulations and other issues among water agencies with overlapping jurisdiction. An effective regulatory system should exist to allow for the decentralization of appropriate aspects of water service production. The major areas this system would have to address are the administration of water rights and allocations, water quality and environmental standards, and prices charged by utilities. This institutional framework would be consistent with the goals of the national water strategy.

The second principle of the World Bank approach is a preference for decentralization and the use of economic incentives in order to achieve more efficient water use and allocation. A major benefit of decentralization is that it relieves the central administrative agencies of some of the burden of making the multitude of operational decisions. As a consequence, more of the scarce administrative resources can be devoted to higher level planning.

In most countries, the urban and agricultural sectors have fixed allocations of water. While these allocations may have been appropriate historically, development leads to a much higher value being placed on water for urban uses. Maintaining the existing allocation leads to a high economic cost, so reallocation should be guided by the government either through better pricing, water trading or another mechanism. Fees should be charged for all water uses as close as possible to the opportunity cost of that use.

The following sections examine how this framework of integrated water resources management might be applied to a particular river basin in Thailand. This case study begins with a description of the water resource situation and current management issues. By exploring some of the complexities of these issues, it will become apparent that their solutions will require an integrated approach. The final sections examine several of these issues in more detail and make some recommendations which would form the beginning of an integrated water management approach.

3. Case Study Background

3.1 Selection of Case Study

The Asian Development Bank (1991) ranked as Thailand as having the worst environmental problems of any country in Asia except for India. Almost all of the environmental problems in Thailand directly or indirectly concern water resources. The most important river basin in Thailand, the Chao Phraya River Basin, was selected as the case study because it illustrates many of the water resource management issues facing Thailand and becoming more common in other developing countries. The Chao Phraya basin comprises both large rural areas and Thailand's capital of Bangkok, a soon-to-be megacity, in a dynamic setting of fast economic development and increasing water scarcity. As will become apparent, there are many opportunities for an integrated approach.

3.2 Thailand Background

The Kingdom of Thailand is located on mainland South-East Asia and is bordered by Myanmar to the west, Laos to the north and east, Cambodia to the southeast and Malaysia and the Gulf of Thailand to the south. The total area is 514,000 km^2. Bangkok, the capital and largest city, sits at the mouth of the Chao Phraya River near the Gulf of Thailand.

3.2.1 Political System

The kingdom of Thailand has politically dominated the Chao Phraya River delta area since the 13^{th} century. It is the only country in the region to maintain its independence from European colonial powers. Economically, however, it was in effect colonized, especially by the British, who controlled the exploitation and trade in Thailand's major commodities—rice, rubber, tin and teak. Eventually, this economic contact with the West, despite the reforms of King Mongkut (1851-1868) and King Chulalongkorn (1868-1910), led to the overthrow of the absolute monarchy. A constitutional monarchy was established instead which continues today. The monarch continues to play an important role in the country's affairs, particularly as a stabilizing influence in times of political upheaval. The present king, Bhumibol Adulyadej, is universally respected (Economist, 1995, p. 4).

Since 1932, the country has been ruled by a succession of military governments with brief periods of civilian rule. Most recently, a military leader General Kraprayoon was persuaded to step down in 1992 by the king and protests in the streets of Bangkok. Elections in September 1992 brought a pro-democracy grouping together in government under the leadership of the Democrat Party leader, Chuan Leekphai (Economist, 1995, p. 5).

The Thai government has strong unitary structure, and administrative power is firmly in the hands of the central government. In form, the Thai government resembles those of the West: various ministries are responsible for such matters as finance, agriculture, education, public health, communications, and justice. Detailed descriptions of government agencies concerned with water resources are given below in Section 5.1. The administration of the 73 provinces (*changwat*) is performed largely by representatives of central government ministries. The only effective local government is provided by cities and municipalities, but, besides the Bangkok Metropolitan Administration (BMA), few have an adequate tax base and so depend on central government grants. Although the BMA has more autonomy than other areas, important local decisions must be approved by the relevant national ministries and often by the cabinet (Potter, 1994).

3.2.2 Economy

Thailand's economy has changed dramatically over the past 25 years. From a purely agricultural economy, Thailand has rapidly grown and developed and will soon join the ranks of the newly industrialized nations. Between 1988 and 1990, gross domestic product (GDP) grew at an average of 11.7% per year, making Thailand the fastest-growing economy in the world. The current GDP growth rate is 7.8% per year for 1991-93 (Economist, 1995, p.12).

Agriculture, once the basis for Thailand's growth, is now generating a fairly small portion of GDP. In 1992, the agricultural sector composed 11.9% of GDP which can be compared with manufacturing, the largest sector, which composed 28.3% of GDP. Nevertheless, the agricultural sector still employs 58% of the labor force (Economist, 1995, p. 14). See Table 1 for summary information.

Table 1 Gross Domestic Product in 1991

Total GDP (Million US$)	GDP Per Capita (US$)	GDP % Growth (1980-1991)	GDP Distribution		
			Agriculture	Industry	Services
$98,261	$1,774	7.9%	12.7%	39.7%	47.6%

Source: World Resources Institute (1994, p. 256)

3.2.3 Population

The estimated 1995 population of Thailand is 58 million (WRI 1994, p. 268). The rate of population growth has slowed considerably. It may now be as low as 1.7% due to a successful family planning program (Economist, 1995, p. 9). Even though Thailand is becoming urbanized and industrialized, it is still a largely rural country. About three-quarters of the population lived in rural areas in 1995 (WRI, 1994, p. 286). The urban population mostly lives in Bangkok, which is more than 50 times the size of the regional capitals of Chiang Mai and Haad Yai (Economist, 1995, p. 9).

3.3 Chao Phraya River Basin

Thailand can be divided into four main regions: North, Northeast, Central and South. The Chao Phraya River is the major river of Thailand and its drainage basin covers most of the North and Central regions. The Chao Phraya River basin, which is the cultural and economic heartland of Thailand, has an area of 170,000 km^2 (one-third of Thailand's total area). See map in Figure 1. About 20 million people (30 percent of the population) live in the basin, nearly 80 percent of which are farmers (Vadhanaphuti et al., 1992, p. 197).

The North region is divided by mountain ranges running north and south, with valleys between the ranges. The four major rivers of the region—the Ping, Wang, Yom, and Nan—merge to form the Chao Phraya. The forests of the northern mountains were once a main source of wood products, such as teak, but many of the forests have been depleted and logging is now banned. Now, the region is approximately 40 percent forest and 40 percent agricultural (Vadhanaphuti et al., 1992, p. 197).

The Central region, sometimes called the Central Plain, consists of two portions: heavily dissected, rolling plains in the north and the flat, low-lying floodplain and delta of the Chao Phraya in the south. The area was formed by the outwash of immense quantities of sediment brought down from the mountains by the Chao Phraya's tributaries, which produced vast fan-shaped alluvial deposits. The densely populated delta contains Bangkok, Thailand's capital and the largest city on mainland Southeast Asia.

The delta floodplain of the Chao Phraya is braided into numerous small channels and is joined by other rivers, in particular the Pa Sak, as the river flows toward its mouth in the Gulf of Thailand. The entire delta was once part of the Gulf of Thailand, but over time the sediments carried down from the north have filled it in. Such silting is a continuing obstruction to river navigation, but it also extends the river's mouth into the gulf by several feet each year (LePoer, 1989). The great deposits of alluvial soils in the river valleys are the most fertile in Thailand. These are replenished annually with sediment washed down by rivers swollen with the annual monsoon rains. Chief among these areas is the delta floodplain of the Chao Phraya, which is the agricultural heartland of Thailand. The area is extremely flat and contains numerous canals used for transportation and irrigation.

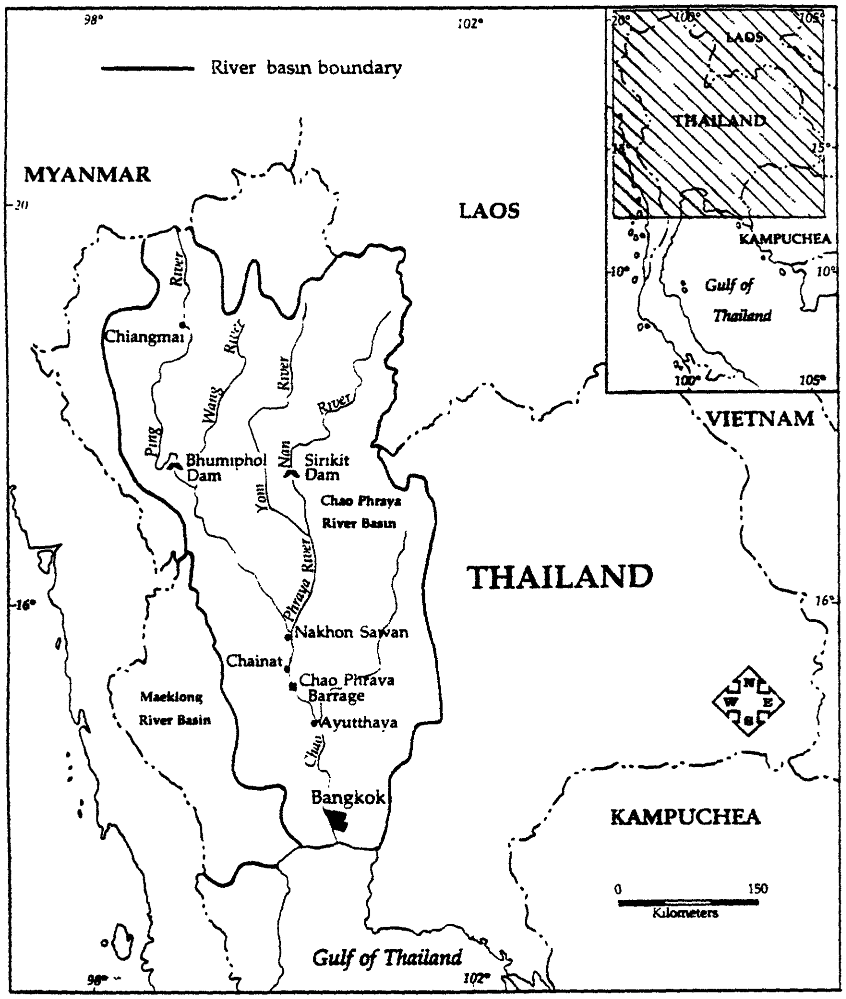

Figure 1 Chao Phraya River Basin

Source: Srivardhana (1994, Fig. 8-2)

3.4 National Water Resources

Thailand's climate is tropical monsoonal. Three seasons can be distinguished based on temperature and rainfall: the hot season, the rainy season and the cold season. The hot season begins in the middle of February and lasts until the middle of May. In Bangkok, the mean temperature during this season is 35 C (Macro Consultants, 1993, p. 2-4). During the rainy season between May and October, 90 percent of the rainfall occurs under the influence of the southwest monsoon often causing heavy flooding. The cold season lasts from November until February, with a mean temperature in Bangkok of 21 C.

The average rainfall for the country as a whole is 1,550 mm/year, or 800 km^3/year, which produces an average surface runoff of 171 km^3/year (Arbhabhirama et al., 1988, p. 92). This means there is 2,950 m^3 of available water per capita per year. France, for comparison, has almost the same total water and per capita availability (World Resources Institute, 1994, p. 329). Of this total, 31.9 km^3, or less than 20 percent, was withdrawn in 1987. As these statistics show, there is no absolute shortage of water in the country. The water resources issues stem from having too much or not enough water at the wrong times or in the wrong places. Reflecting Thailand's generally rural makeup, about 90% of water withdrawn is used for agriculture, while 4 percent and 6 percent are withdrawn for domestic and industrial uses, respectively (World Resources Institute, 1994, p. 346). See Figure 2 for a breakdown of water withdrawals by sector as a percentage of total available water.

The Chao Phraya is the most important river in Thailand receiving an average annual rainfall between 1,000 and 1,400 mm/year and having an average annual discharge at the mouth of 30.3 km^3 (Arbhabhirama et al., 1988, p. 93). The monthly runoff is shown in Figure 3. In size, however, the Chao Phraya is dwarfed by the Mekong with a mean discharge of 473.5 km^3/year as it passes through the North region of Thailand (World Resources Institute, 1994, p. 333). Another important river is the Maeklong which has an average annual discharge of 13.4 km^3 in a drainage area of only 33,000 km^2 (Arbhabhirama et al., 1988, p. 95). Both the Mekong and Maeklong are being considered as sources of imported water for the Chao Phraya basin. The Mekong is an international river, however, which is subject to a number of international agreements. Additional information about other selected major rivers is given in Table 2.

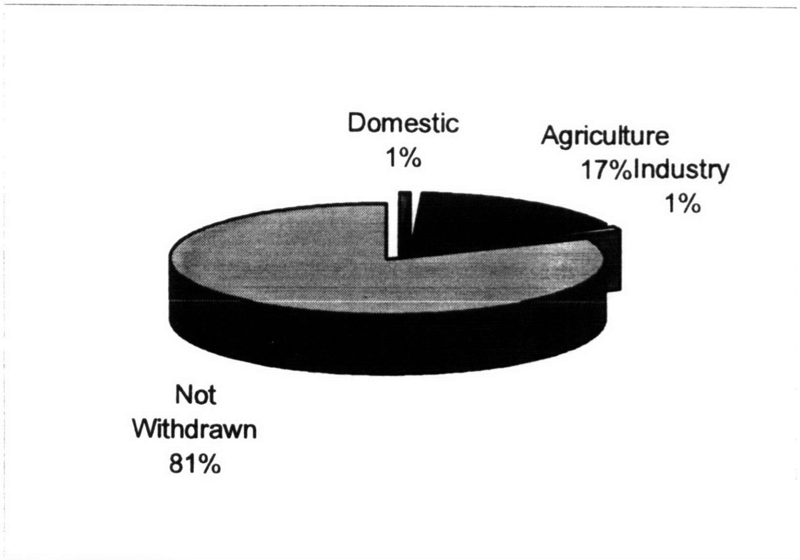

Figure 2 National Water Withdrawals By Sector

Total renewable water resources available: 171 km^3/year
Source: World Resources Institute (1994, p. 329); Arbhabhirama (1988, 93)

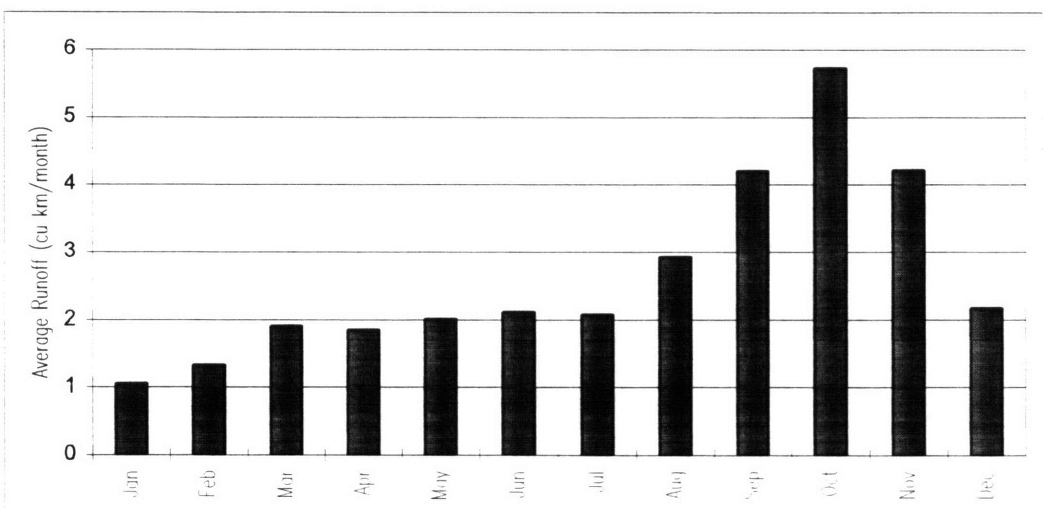

Figure 3 Average Monthly Runoff in Chao Phraya Basin

Source: Global Runoff Data Center

Table 2 Basin Area and Mean Annual Runoff of Selected Major Rivers

River	Gauging Station	Basin Area (km^2)	Runoff (km^3/year)
Chao Phraya	Nakhon Sawan	110,570	24.2
Mekong	Mukdaham	391,000	473.5
Maeklong	Kanchanabburi	26,450	12.3
Nan	Phitsanuloke	25,191	8.7
Ping	Kam Pan Petch	42,300	7.6
Wang	Wang Krai	10,204	1.4
Yom	Kuang Luang	13,214	2.6

Source: World Resources Institute (1994, p. 333); Arbhabhirama et al. (1988, p. 96)

4. Water Resource Issues in the Chao Phraya River Basin

4.1 Introduction

This section describes the current state of water resources use and management in the Chao Phraya River Basin. In general, the demand for water is increasing in all sectors and water conflicts are becoming more severe. The purpose of this section is to show how complicated the water resource situation is in Thailand and to draw attention to the relationships among different water resource issues.

The main water users coming into increasing conflict are: Bangkok, the Central Plain Farmers, the Electricity Generation Authority of Thailand (hydropower generation), and the Northern provinces (both agricultural and domestic uses). This conflict can be illustrated by considering the situation at the beginning of the Chao Phraya River at the town of Nadhon Sawan. This is near the division of the Northern and the Central regions and right below the confluence of the Ping and Nan Rivers. The Northern users have withdrawn water for their needs and most hydropower potential has been exhausted.

According to Table 2, the mean annual runoff of the Chao Phraya at Nakhon Sawan is 24.2 km^3. However, this amount is decreasing due to increasing withdrawals in the Northern region. Recently, the available water was only 20.0 km^3/year (Tingsanchali et al., 1995, p. 92). This water is completely used—it is withdrawn for urban, industrial or agricultural use or is left in-stream to provide for navigation and the prevention of salt-water intrusion. The percentages for each use are shown in Figure 4.

This water scarcity could have an effect on Thailand's economic growth. A very simple example is how the cost of water can affect foreign business investment. An article in the *Economist* (Into China, 1996) compared the costs of running a business in Japan, Thailand and China. See Table 3. In general, the costs of business in Thailand were much less than those of Japan with two exceptions—short-term interest rates and tap water.

As will be described in more detail in the following sections, there is unmet and growing demand for water in each sector. In addition, the amount of water entering the Central Plains from the North will probably continue to decline as it has in the past. Figure 5 shows decreasing storage levels in the two major dams feeding the Central Plains. Figure 6 shows the reason, decreasing inflows. The result is water conflict which is putting a strain on the current water management system.

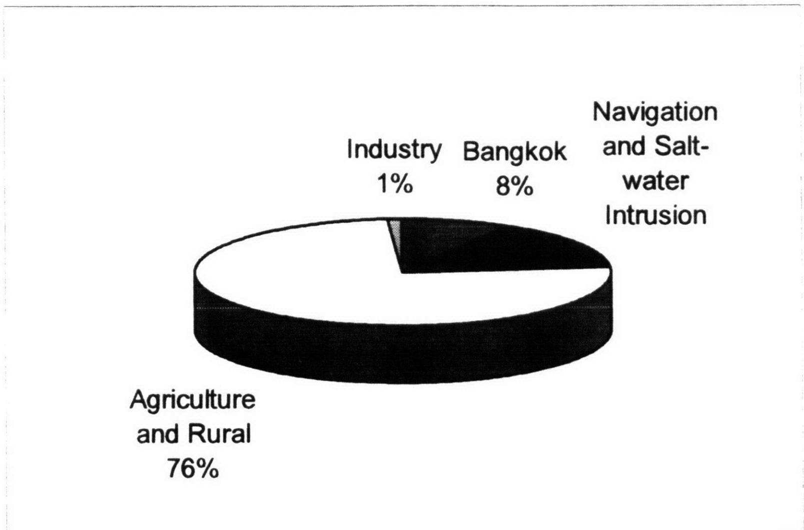

Figure 4 Water Use in Central Plains

Source: Tingsanchali (1995)

Table 3 Business Cost Comparison (Japan=100)

	Japan	Thailand	China
Wages	100	6	4
Short-term interest rates	100	1,188	1,513
Plant-site land	100	1	10
Construction cost	100	45	-
Overland transport	100	25	-
Customs expenses	100	33	130
Warehouse leasing	100	20	20
Power	100	45	28
Tap water	100	100	1
Office operating cost	100	70	20
Corporation tax	100	80	88

Source: Economist (1996)

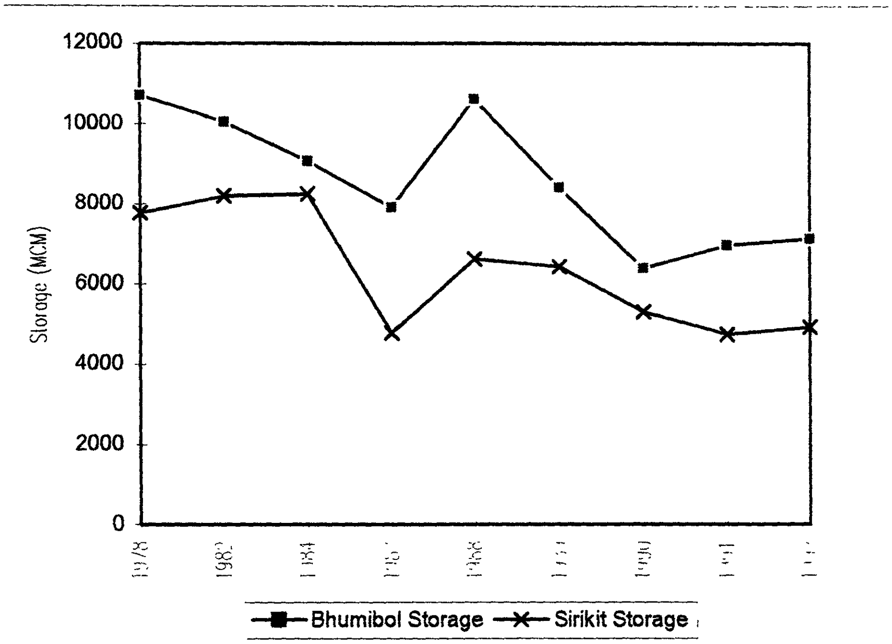

Figure 5 Storage Levels in Bhumibol and Sirikit Dams

Source: Van Beek (1995, p. 151)

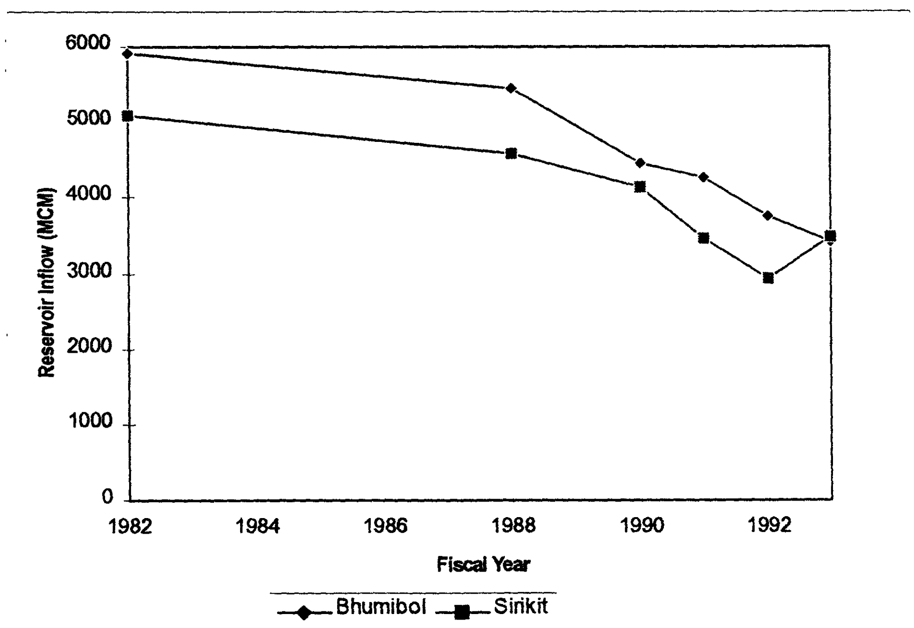

Figure 6 Inflows Into Dam Reservoirs

Source: Van Beek (1995, p. 153)

4.2 Urban Water Supply and Sanitation

4.2.1 Bangkok Metropolitan Region

The Bangkok Metropolitan Region (BMR) is the major urban center of Thailand. It consists of Bangkok and parts of the five adjacent provinces of Nonthaburi, Samut Prakan, Nakhon Pathom, Pathum Thani, and Samut Sakhon covering a total of approximately 7,758 km^2. The city of Bangkok, or the Bangkok Metropolitan Administration (BMA), is located in the middle of the BMR and occupies 1,565 km^2. The BMR was established for the planning and management of public infrastructure for Bangkok and the five neighboring cities. The cities are expanding towards and the region is becoming one megacity. Each province, however, is a separate political unit under control of the national government (Srivardhana, 1994, p. 131).

Bangkok began as a compact city located on the east bank of Chao Phraya River about 25 km upriver from the Gulf of Thailand. It is now the center of growth in Thailand. The BMR has a rate of economic growth about 3% higher than the national average growth rate. These growth rates are expected to continue, so Bangkok may have one of the world's fastest growing economies over the next decade (BMA/MIT, 1996, p. 1). In 1995, the estimated population of the BMA was 7.9 million and that of the BMR was 11 million. Although previously much higher, the current growth rate is now just under 3 percent (BMA/MIT, 1996, p. 4). Projected populations for the BMA and the BMR are shown in Table 4.

Table 4 Projected Populations

	1995	2000	2005
BMA	7.9	9.1	10.3
BMR	11.0	12.7	14.5

Source: BMA/MIT, 1996, p. 14

4.2.2 Water Supply

4.2.2.1 Administration

The administrative responsibilities for water supply and sanitation within the BMR are split among several agencies. The Metropolitan Waterworks Authority (MWA) is responsible for the production and delivery of piped water supply within the BMA and the two provinces of Nonthaburi and Samut Prakan, an area covering 3,080 km^2. In the other three provinces of the BMR, as well as the rest of the country, the Provincial Waterworks Authority (PWA) is responsible for water supply, although local governments and municipalities play a significant role. More detail about the many agencies involved in water management is given below in Section 5.1.

4.2.2.2 Current Water Supply System

The only surface water source for the BMR is the Chao Phraya River. The water is withdrawn from the river at Samlae and conveyed by canal to the treatment plants of the Metropolitan Waterworks Authority (MWA). Currently, approximately 3.56 million m^3/day of raw water is withdrawn for water supply (BMA/MIT, 1996, p. 92). The remaining water in the river is used for irrigation and the prevention of salt-water intrusion in the Chao Phraya and Thachin Rivers. There are plans to augment that source with interbasin transfers which are described below in Section 4.7. These interbasin transfers will increase the amount of raw water available to the MWA.

The pumping station at Samlae, Pathum Thani Province is 90 km upstream from Gulf of Thailand, beyond the reach of salt-water and pollution. Almost all of the raw water is conveyed by a 60 m^3/s canal (Klong Prapa) to the Bang Khen and Sam Sen treatment plants and from there to the Thon Buri Water Treatment Plant through a 600 mm diameter pipe (BMA/MIT, 1996, p. 92).

The MWA also extracts groundwater for the municipal supply from deep supply wells. In 1995, MWA extracted 0.24 million m^3/day for the municipal system. An additional 1 million m^3/day is extracted from private wells in the service district of the MWA. Most of the private extraction is illegal and conducted by the industrial sector. The safe yield of the groundwater basin (i.e., when the pumping rate equals the recharge rate) is estimated to be 0.6 MCM/day. Thus, current extraction rates exceed the safe yield by over 100%. The result has been a dropping water table and serious ground subsidence problem.

The total production by the MWA in 1995 was 3.8 million m^3/day. Of this, 93.3% was from the Chao Phraya River and 6.7% was from groundwater. More details are provided in Table 5. There are also significant private groundwater extractions, which are discussed in more detail in the next section. If these extractions are included, the total production from the MWA service are is 5.08 million m^3/day. About 75 percent of this total is surface water. See Figure 7.

Water service was provided to about 1.23 million connections representing 6.2 million people. Within the BMA, approximately 800 km^2 (52% of BMA area) is supplied through the existing MWA system. There are some industrial areas and large residential subdivisions particularly on the eastern suburban edge of the BMA which are not serviced. Another deficiency is that some parts of the distribution system suffer from leaks, breakage and unauthorized tapping which results in unreliable service and insufficient water pressure, especially in the outermost service areas (BMA/MIT, 1996, p. 92). Another area of concern is the high level of unaccounted for losses, which were about 33% in 1992 (BMA/MIT, 1996, p. 103). This is an improvement from the 43% reported in 1985 (Srivardhana, 1994, p. 139).

The MWA has a Masterplan for Water Supply and Distribution to guide future expansion projects. Many expansion projects are already under construction. See Table 5 for information on expansion projects at water treatment plants. Water production is planned to increase to 6.08 million m^3/day by 2007 and to 7.90 million m^3/day by 2017 (BMA/MIT, 1996, p. 93).

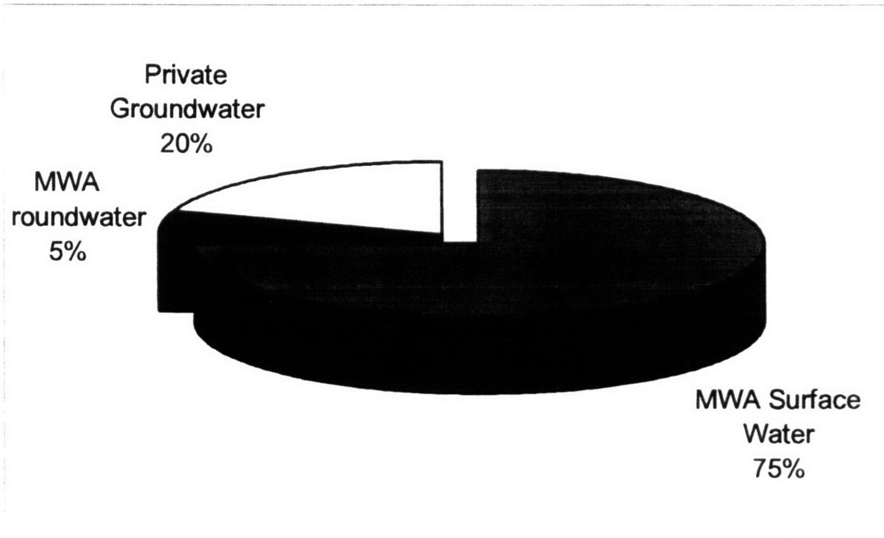

Figure 7 Water Production in the MWA Service Area.

Total Production: 5.08 million m^3/day
Source: BMA/MIT (1996)

Table 5 MWA Water Production System, 1995

Water Treatment Plant	Current Capacity (million m^3)	Future Capacity (million m^3)	Future Capacity Date
Bang Khen	2.77	3.17	December 1996
Sam Sen	0.55		
Ton Buri	0.16		
Mobile Plant	0.08		
Mahasawat	NA	0.40	Under testing
Deep Groundwater Wells	0.24		
Total Production	3.80		

Source: Adapted from BMA/MIT (1996, p. 94)

4.2.2.3 Groundwater and Land Subsidence

Withdrawal of groundwater within the BMR has been reported since the 1920s. These early withdrawals were in small amounts and from shallow wells since the water table was still very high. With the inauguration of the first National Economic and Social Development Plan in 1961, large groundwater extractions began. Water demand grew rapidly due to Bangkok's expansion. The MWA used groundwater for local uses in areas not yet connected to the central supply service. Water users, including households and industries, who could not wait for MWA to provide a water supply, constructed their own groundwater wells for private supplies. The MWA also began withdrawing groundwater as a raw water source for its piped supply. In 1963, the MWA was the largest groundwater user, pumping approximately 0.3 million m^3/day (Srivardhana, 1994, p. 136). Very soon after this year, private well extractions exceeded those of the MWA.

The aquifers in the Bangkok area are very productive. Investigations have revealed high transmissivity alluvial deposits of 50 to 100 meters thick interspersed with very dense clay layers at least to a depth of 650 meters (Macro Consultants, 1993, p. 2-23). The impermeable clays layers have for the most part prevented the aquifers from being contaminated by surface discharges. Excessive drawdowns, however, have lead to salt-water intrusion in the upper aquifers particularly in the southern portion of Bangkok. As a result, shallower wells have been closed and most extractions are from deeper zones.

Until the passage of the Groundwater Act in 1977, statistics for private groundwater extraction were not available. The Act was passed because of concern over excessive groundwater use, especially in the BMR. In areas designated as groundwater zones, the Act required that a permit be obtained from the Department of Mineral Resources for well installation or groundwater withdrawal from a well (Srivardhana, 1994, p. 146). A summary of well pumping in the BMR recorded by the Department of Mineral Resources (DMR) is shown in Figure 8. In 1995, the official estimate of private groundwater extraction in the BMR was 1 million m^3/day (BMA/MIT, 1996, p. 92). According to a study by Sethaputra et al. (1990, p. 51), however, this is almost certainly an extreme underestimate. The study estimated water use in 1989 from per factory make-up water consumption statistics and estimates of industrial wastewater discharge. The estimated amount of private extraction was 2.9 million m^3/day. For the same period, the official DMR records from over 9000 wells show extractions between 1.2 million m^3/day and 1.4 million m^3/day. The difference was attributed to unreported groundwater pumping.

Since the safe yield was estimated at 0.6 million m^3/day, the aquifer has been in a state of overdraft for at least 20 years. The water level, originally near the ground surface, has been falling steadily. In 1959, the lowest water table elevation measured in Bangkok was 12 m below the ground surface. After 1967, the water level in the same spot was 42 m below ground surface and by 1982 the level was 52 m below ground surface. This excessive groundwater withdrawal is a major factor causing land subsidence in the BMR. Subsidence rates between 5 and more than 10 cm/year have been measured throughout the region. The area of highest subsidence is in eastern Bangkok where the city's most rapid expansion took place and the MWA was least able to provide supplies (Srivardhana, 1994, p. 137). Consequently, this is probably the area with the most private groundwater extractions.

The Groundwater Act was amended in 1985 in response to the land subsidence problem. It mandates the phasing out of groundwater use in the BMR by 1998. As shown in Figure 9, some progress has been made. The MWA has reduced its extractions by 13% between 1990 and 1995. According to official statistics, private use has declined 31% over the same period, although the accuracy of these statistics is uncertain. The total groundwater use is still 1.24 million m^3/day, which is more than twice the level of safe yield. It seems unlikely that the target of the 1985 Groundwater Act will be met.

Groundwater continues to be extracted in violation of government policy mostly by industrial users. They use groundwater because MWA service is unreliable or doesn't exist and because groundwater is significantly cheaper. There have been a number of studies analyzing the problem of excessive groundwater extraction in the BMR. See, for example, Potter (1994), BMA/MIT (1996) and Sethaputra et al. (1990). They all concluded with similar recommendations: 1) expand the MWA piped water supply, 2) reduce consumption levels through water conservation programs, 3) improve enforcement of groundwater regulations, and 4) improve economic incentives through water pricing changes.

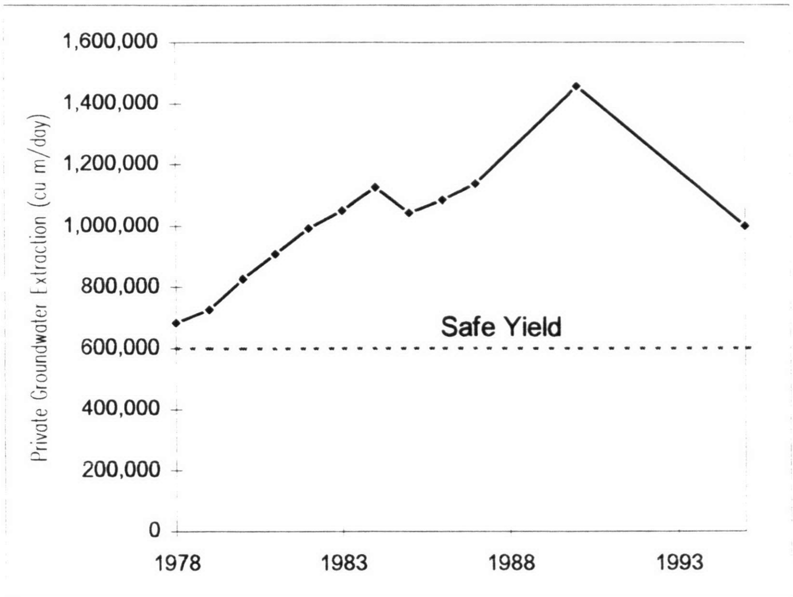

Figure 8 Private Groundwater Extractions in the BMR

Sources: BMA/MIT (1996, p. 92); Macro (1993, p. 2-63); Sethaputra (1990, p. 52)

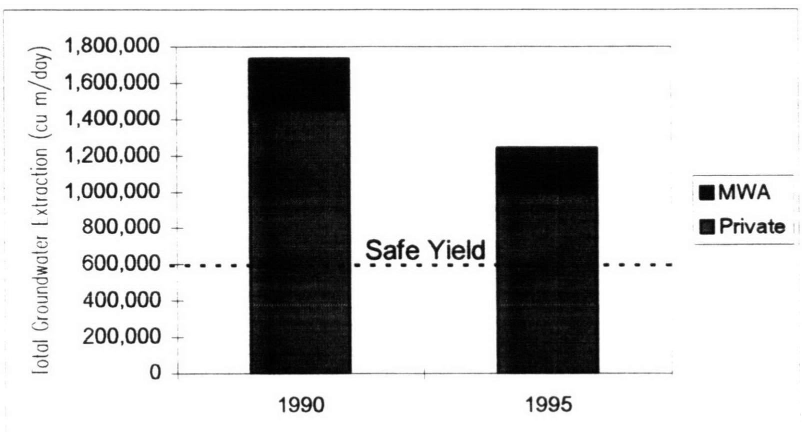

Figure 9 Total Groundwater Extractions in the BMR

Sources: BMA/MIT (1996, p. 92); Macro (1993, p. 2-63); Sethaputra et al. (1990, p. 52)

4.2.3 Wastewater Collection and Treatment

The BMA's Department of Drainage and Sewerage (DDS) is responsible for drainage, flood protection and wastewater systems within the BMA. More detail about the many agencies involved in water management is given below in Section 5.1. Currently, there is only one sewerage collection and treatment system in operation. The capacity of this system is 30,000

m^3/day which is sufficient to serve about 100,000 people, or less than two percent of Bangkok's population. Five additional wastewater collection and treatment systems are planned or being built with a total additional capacity of 1,000,000 m^3/day (MIT/BMA, 1996).

The sources of wastewater in the BMR are estimated to be 75 percent residential and 25 percent industrial (Potter, 1993, p. 71). The residential wastewater is composed of untreated or partially treated sewage. Although very few households are connected to a central sewerage system, most have some form of subsurface leaching system, usually a septic tank with leaching pits. Unfortunately, the impermeable clay and high groundwater table of the region does not permit very much leaching to take place, so much of the septic tank effluent flows through surface drainage into klongs or the Chao Phraya River. The efficiency of residential septic systems is only about 30-35 percent. Furthermore, some residents discharge their wastes directly into surface waters.

Although currently industry produces only about one-forth of the wastewater in the Chao Phraya Basin, it is expected to grow rapidly. Most industry in Thailand is concentrated in the Samutprakarn region between Bangkok and the Gulf of Thailand. Although all industrial facilities are supposed to provide on-site treatment of wastewater, the klong network in this region is still heavily contaminated. Some industries, owned by international corporations, have properly functioning on-site treatment systems, but most do not (Ludwig and Gunaratnam, 1994, p.273). The possibility of toxic effluents is also an increasing concern.

The government's control strategy is: 1) a permit system operated by the Department of Industrial Works, which includes requirements for on-site treatment; and 2) environmental impact assessments (EIAs), which the Ministry of Science, Technology and Environment requires every environmentally sensitive industry to submit every four years. Enforcement of both measures has been lacking. A central hazardous waste treatment facility in the Samutprakarn region was built under Department of Industrial Works sponsorship with two more planned. Ludwig and Gunaratnam (1994, p. 273) predict that these plants will not be effective unless enforcement is significantly improved.

As described in the following section, water quality in the Chao Phraya especially around Bangkok is very poor. Since most of the wastewater comes from the residential sector and it is impossible to effectively treat it on-site, a comprehensive wastewater collection and treatment system is needed. Numerous studies of the problems and proposals for wastewater systems have been written in the past, but the costs have been prohibitive. Recently, the government has decided to proceed with a comprehensive wastewater system, described in the wastewater management master plan for the BMR written by Macro Consultants (1993). Currently approved projects will provide a treatment capacity of 1,000,000 m^3/day serving a population of about 2,000,000. Additional planned projects will add an additional 1,800,000 m^3/day of capacity. The total capital cost of all projects is estimated at almost 40 billion baht, or $1.6 billion (Macro Consultants, 1993, p. 6-58).

4.3 Water Quality

Water quality monitoring at 32 monitoring stations on a 380-km reach of the lower Chao Phraya River has been performed by Office of the National Environmental Board since 1981 (Macro Consultants, 1993, p. 3-15). Three levels of water quality standards have been set for the Chao Phraya, which are applied at three different portions of the river. The reaches are defined by distances measured upriver from the Gulf of Thailand as follows: lower reach (km 7 to 62), middle reach (km 62 to 142) and upper reach (km 142 to 379). Water quality standards have been defined for dissolved oxygen, biochemical oxygen demand and coliform bacteria. See Table 6. The standards become less stringent on the lower reaches of the river as it passes through Bangkok.

The standards for coliform bacteria and biological oxygen demand have generally been met in all portions of the river, but the standard for dissolved oxygen has not with the lower portion the most polluted (Macro Consultants, 1993, p. 3-18). Results of monitoring for DO and BOD in the lower river are shown in Figure 10. While BOD levels are usually under the permissible levels, the dissolved oxygen levels are close to zero. Natural water has a DO level of about 7 mg/l. There are adverse effects on some fish species at levels below 4 mg/l, and on all fish species at levels below 2 mg/l. When the DO approaches zero, the water becomes black and foul smelling. In many parts of the Chao Phraya and klongs, these are the conditions reported (Macro Consultants, 1993, p. 1-1). Most aquatic life is unable to survive and Bangkok residents are unable to use the klongs for their traditional uses of washing, bathing and fishing.

The effect of poor water quality on aquatic ecosystems was documented by Macro Consultants (1993). The abundance and diversity of benthic organisms has declined dramatically in the Bangkok area. The number of fish species in the Chao Phraya has decreased from 127 in 1955 to 18 in 1991. There have also been adverse effects on aquaculture near the Gulf of Thailand. For example, 90 percent of the shrimp farms have shut down due to water pollution (Macro Consultants, 1993, p. 3-24).

Another important water quality consideration is the control of salt-water intrusion into the Chao Phraya and Thachin Rivers. The main purpose is to protect agriculture in the BMR, particularly orchards in the Nonthaburi Province, which is famous for its fruit production (Srivardhana, 1994, p. 136). These orchards would be destroyed if the sea water from the Gulf of Thailand penetrated 40-50 km upstream. To prevent excessive intrusion, required flows are 50 m^3/sec in the Chao Phraya and 45 m^3/sec in the Thachin. This is equivalent to a total of about 3 km^3 annually. Maintaining this flow also dilutes the large amount of wastewater discharged into the rivers, thus providing a water quality benefit.

The water quality of the lower Chao Phraya has important effects on water supply. The most obvious is that the degradation of raw water supplies increases the costs of water treatment. However, there may also be an adverse effect on the water after it is in the water supply distribution system because of breaks and leaks in the system. Groundwater may be degraded by the polluted surface water. Another problem caused by the low water quality in the lower Chao Phraya is that industrial users cannot substitute a private surface water supply for their present groundwater supply. This places pressure on the MWA to provide water for the growing industrial sector and makes eliminating groundwater extractions in BMR more difficult.

Table 6 Water Quality Standards for the Chao Phraya River

Standard Level	River Reach (km from mouth)	DO (mg/l)	BOD (mg/l)	Coliform Count (MPN/100 ml)
4	7 to 62	2	4.0	-
3	62 to 142	4	2.0	20,000
2	142 to 379	6	1.5	5,000

Source: Macro Consultants (1993, p. 3-15)

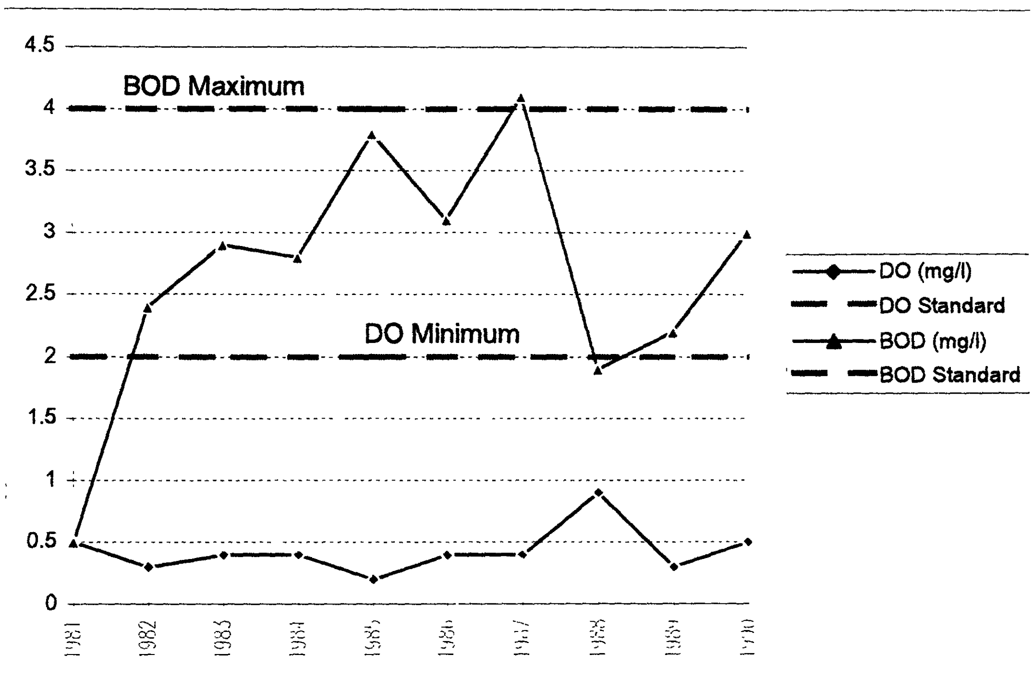

Figure 10 Dissolved Oxygen and Biological Oxygen Demand Levels on Lower Chao Phraya

Source: Potter (1993, p. 66)

4.4 Flood Control

4.4.1 Introduction

The flat, low-lying deltaic plain formed by the Chao Phraya River basin has always been subjected to seasonal flooding. In the past, this flooding was beneficial for agriculture and not damaging to residents who lived in stilt-elevated houses and used boats for transportation. The urbanization of Bangkok and surrounding areas has made floods much more costly, and potential flood damages continue to rise with Bangkok's development. The geographical setting make flood control difficult and expensive.

The institutional framework may also make flood control more difficult. According to the UN, there is no one agency which is responsible "for carrying out integrated and comprehensive flood control activities in Thailand, but several agencies, acting more or less independently, execute related activities" (UN ESCAP, 1990, p. 11). Structural measures for flood protection in Bangkok are the responsibility of the Department of Drainage and Sewerage under the Bangkok Metropolitan Administration. EGAT is involved in flood forecasting and the RID controls the upstream dams, water gates and pumps.

The flooding in Bangkok in 1995 was the worst in over a decade. The estimated flooded area was 1,133 km^2 (72 percent of the BMA) affecting over 2.6 million people (BMA/MIT, 1996, 85). Damages for the nation were over 5 billion baht ($200 million). In the nation as a whole, crops in about 10 percent of cultivated area were destroyed and 175 were killed (Vatikiotis, 1995).

4.4.2 Factors Influencing Flooding

The causes of the floods are well known: heavy rainfall and the overflow of the Chao Phraya River (BMA/MIT, 1996). The Bangkok plain is extremely susceptible to flooding because it has an average elevation of 1-2 m above mean sea level (MSL), with some locations up to 0.5 m below MSL. High water levels in the Chao Phraya result from high discharge from the north, occurring mainly during September through December, and high tides in the Gulf of Thailand, occurring mainly in June, July and November through January. Heavy rainfall occurs during the monsoon season between May and October. The worst floods occur when high river stage and heavy rainfall coincide.

There are also three contributing factors to the flood problem. First, drainage capacity is reduced by the filling of klongs. Second, ground subsidence due to groundwater overdraft is making the flooding worse. Third, run-off is increased due to land-use changes. Areas around Bangkok that were formerly used for agriculture are being developed for urban uses. If these three factors could be controlled, flood damage would be mitigated.

The network of klongs are a critical element of the surface drainage system—they temporarily store water while allowing it to discharge into the rivers at absorbable rates. Most klongs flow east-west and connect with important rivers, such as the Chao Phraya and Tha Chin. The klongs are used for transportation and flood irrigation of rice and other crops. Some control structures (e.g., gates, locks, pumping stations) have been constructed for navigation, drainage, flood control, and to prevent salt-water intrusion (BMA/MIT, 1996, p. 116).

Before urbanization, the natural inundation of the delta by annual river floods, high tides or local rainfall was not a problem because it was part of the annual rice growing cycle. Rainfall was absorbed and retained on the land, which regulated flow into the klongs. Urbanization increased the amount of impervious surfaces, and so increased runoff in the klongs. Since the plain is flat, klong gradients and flow capabilities are small, there are surges which overflow the banks (BMA/MIT, 1996, p. 116). Many klongs have been filled in to accommodate roads and buildings, which has disturbed the drainage network. Sometimes piped drainage systems have been installed below or adjacent to roads, but these do not usually have comparable flow capacities.

4.4.3 Flood Protection in Bangkok

The first major flood management plan for Bangkok was prepared by Camp, Dresser & McKee in 1968. Prior to the large Bangkok flood of 1983, flood control and drainage facilities were fairly limited. In response to the extensive flood damage in 1983, the government installed significant structural measures including polders and pumping stations (UN ESCAP, 1990, p. 9). Since then numerous additional flood control studies have been performed. Although some additional structural measures have been implemented, many proposed measures have not been due to lack of financial resources. The largest-scale project proposed is the Chao Phraya 2, with a project area of 1,400 km^2. Designed to protect against the 100 year flood, the project includes a 60-km diversion canal, a diversion dam at Pak Kret and a tidal barrier at the mouth of the Chao Phraya (Thai-Austrian Consortium, 1986). Non-structural measures have been adopted by the BMA, but success has been limited due to lack of control over land-use in the rapidly growing city.

Since 1979, flood forecasting has been conducted by EGAT for use in dam operation (UN ESCAP, 1990, p. 10). This flood information is transmitted to other agencies involved in flood control. The Civil Defense Division of the Department of Local Administration is responsible for disseminating flood warnings to local government offices, other organizations and the residents of Bangkok. EGAT uses a flood forecasting system which is based on a model developed by Asian Institute of Technology in 1978. The model predicts the maximum water level at the Memorial Bridge in Bangkok.

In eastern Bangkok, existing flood protection infrastructure includes polder boundaries, roads used as barriers, dikes and control gates. There is an extensive drainage system including approximately 52 pumping stations to transfer water to nearby klongs or the Chao Phraya. The total capacity of these pumping stations is 370 m^3/s (BMA/MIT, 1996, p. 98). The master plan for this area focuses on increasing the capacity of conveyance system and improving the polder system. In western Bangkok, the infrastructure consists of a polder boundary and land barriers. Water levels in the polder are controlled by pumping stations. Some of the klongs in the area are clogged reducing their conveyance capacity, so the King of Thailand has proposed to clean out these klongs in order to improve drainage. The Bangkok Plan (BMA/MIT, 1996) suggests that a plan be formulated to improve the flood protection infrastructure in western Bangkok. Currently, the infrastructure is inadequate to keep flood waters out of the area.

The Bangkok Plan makes three general recommendations to improve flood control in Bangkok. They are: 1) the imposition of on-site retention requirements, 2) implementation of projects to increase klong conveyance capacity, and 3) the creation of retention ponds in combination with parks. These are relatively low-cost measures compared with the projects proposed in the other plans.

4.5 Irrigation and Hydropower

4.5.1 Traditional Irrigation Systems of the North

Until about 25 years ago, the mountains in northern Thailand in the upper part of the Chao Phraya Basin were mostly occupied by tribal groups who had settled there in the last few centuries. These groups practiced shifting cultivation, also called slash-and-burn or swidden agriculture. This type of agriculture is based on cutting living vegetation in the early part of the dry season, letting it dry, burning it late in the dry season and then planting a crop in the ashes early in the wet season. After harvest, the plot is left fallow for many years or abandoned because the soil will no longer support crops. Shifting cultivation can be sustainable and efficient in the relatively infertile upland soils as long as population densities are low enough. In stable and productive systems fields must be rotated every 10-15 years. When population pressures increase, the period of rotation goes down, and the soils become exhausted and erosion becomes a major problem (Collins, 1991, p. 30).

Recently, large numbers of marginalized lowland Thais have migrated into the hills and now outnumber hilltribe members by approximately six to one (Tongdeelert, 1991, p. 101). The lowland Thais are settled in ethnic Thai farming communities along the relatively fertile and well-watered valleys, which cover less than 10 percent of the northern regions area. This increasing population pressure has resulted in increased deforestation and degradation of upland watersheds.

The lowland Thais in the North traditionally follow a way-of-life that is well-adapted to the conditions of region. In the valley bottoms, wet-rice agriculture is practiced, and in the villages further up the slopes, pigs, ducks and chickens are raised and vegetables grown. Above the villages, rice, beans and corn are grown in hill fields. In the forests further up the hillsides, the lowlanders hunt wild game and collect herbs. The forests are also used for grazing cattle and buffalo and as a source of wood for utensils, cooking fuel, and construction and farming tools. Fish are present in the irrigation system and wet-rice fields for both food and pest-control (Tongdeelert, 1991, p. 101).

At the basis of this type of village life is a traditional system of irrigation called *muang faai*. It solves the problem of how to use the fast, heavy-flows from mountain streams for transplanted wet-rice agriculture. The system draws water from the stream at a point above the highest rice field and returns water if necessary to the stream below the lowest field. A reservoir at the top of system is created using a weir made of bunches of bamboo or saplings which is permeable enough to allow sediment to pass through. The height of weir is set each year depending on projected water needs. The water in the reservoir is then diverted through a main canal into a branching network of smaller channels which supply the fields. The amount of water distributed to each farmer's field is regulated by adjusting the size and depth of the side-channels (Tongdeelert, 1991, p. 102).

The *muang faai* system requires a great deal of collective management and cooperation. The numerous rules governing the use of water and land in the system are determined at a yearly meeting. For the most part, water is treated as common property. Besides the fundamental principle that everyone in the system must get enough to survive, water priorities are assigned in a many different ways in different communities. For example, priority is sometimes given to farmers who were on the land first or to farms which are cultivating rice as opposed to cash crops (Tongdeelert, 1991, p. 103). Each farmer is also responsible for maintaining the system. Every year, channels must be cleared and weirs reconstructed, which for larger systems amounts to a significant amount of work.

Theft of water is punished by fines. The amount of the fine depends on how scarce water is in that season. There are also penalties for misuse of upstream watersheds, for example, cutting down a tree for sale on the market or other personal uses not connected with making tools for or repairing the *muang faai* system. The social stigma associated with violations is perhaps more effective than the fines in discouraging misuse of the system.

Muang faai systems are still present along almost every stream in Northern Thailand and in some areas in the central region. They vary in size from a five-family system with one and a half hectares of rice fields to multi-community systems irrigating 1500 hectares. For example, in Chiang Mai province in the mid-1980s, about 2000 *muang faai* systems were irrigating 96,000 ha while the four large dams installed by the Royal Irrigation Department (RID) were irrigating 52,000 ha. In the North as a whole, *muang faai* systems are dominant in as much as 80 percent of the agricultural areas with the remainder irrigated with modern systems by the RID (Tongdeelert, 1991, p. 102).

The traditional *muang faai* system has come under a great deal of pressure as Thailand has grown and developed. Extensive government-sanctioned logging has lead to depleted forests in many *muang faai* areas. The deforested watersheds release water less steadily making the system more difficult to operate. In addition, the promotion of cash-crops such as ginger, baby corn, soybeans, cabbage, carrots and potatoes has encouraged forest clearing and pesticide use. Many of the wooden weirs have been replaced by concrete dams under an extensive modernization program of the RID. Increased erosion and runoff have caused siltation of the new dams, making system maintenance more difficult and expensive because special machinery must be rented to clean out the silt. If the maintenance burden becomes too large, the system is abandoned and the villagers are forced to earn income by illegally cutting wood in the forest or clearing new land—both of which undermine the *muang faai* system still further.

On the other hand, the traditional system has a number of advantages. It is flexible and responsive to local needs, much more so than irrigation systems based on large dams. It is essentially an integrated watershed management scheme which considers the interactions among forest, land and water resources within the watershed area. If it can be adapted to modern conditions, the *muang faai* system may be a effective way to manage resources on the watershed scale.

4.5.2 Early Irrigation Projects in the Lower Basin

Thai farmers in the lower basin have traditionally relied on rain and flood water for rice cultivation, but the amount needed was not always received because of fluctuating rainfall and runoff. Starting about 1500, a number of klongs, or canals, were dug in the Central Plain to provide transportation routes and to carry flood waters from the Chao Phraya to the fields (Takaya, 1987, p. 182). Beginning in the 1870s, King Chulalongkorn began modernizing Thailand's administration and economy. Rice was becoming an important export crop and source of revenue. As part of this effort, many new klongs were constructed in the lower basin to open up forested land to rice cultivation and provide additional transportation routes to bring the crops to market. By the early 1900s, an extensive network of klongs had been constructed. They did not, however, form a controlled irrigation system, rather simply a distribution net with the amount of water available dependent on the level of the rivers. Records covering the period between 1830 and 1930 show that water was insufficient for cultivation in about one-third of the years (LePoer, 1987, p. 153).

The first controlled irrigation project was completed in 1924 on the Pasak River. The dam came to be called the Rama VII Dam and is located northeast of Ayutthaya in the lower basin. After this project, the focus of government efforts under the new Royal Irrigation Department, formed in 1927, was to improve irrigation facilities in the North. A series of four dam projects provided irrigation for 51,700 ha in Chiang Mai-Lamphun basin by 1940. There was no further significant irrigation work in the lower basin until the giant Greater Chao Phraya Project was begun in 1950 (Van Beek, 1995, p. 129).

4.5.3 Greater Chao Phraya Project

By far the largest irrigation project in Thailand is the Greater Chao Phraya Project. The centerpiece of the project is the Chao Phraya Dam built at Chainat. It is also sometimes called the Chainat Dam or Chainat Barrage. The dam, completed in 1957, has a total length of 237.5 m with a series of sixteen sluice gates providing a maximum high-water discharge of 3300 m^3/sec (Takaya, 1987, p. 238). Combined with the extensive klong network, it composed what was then considered Asia's largest irrigation project (Van Beek, 1995, p. 139). The project was expanded in phases until now it provides irrigation for 1.25 million ha. This brings the total irrigated area to 2.8 million ha for the Chao Phraya Basin—ensuring that it remains the rice bowl of Thailand (Tingsanchali, 1995, p.91). In addition to dams, more than 5,000 kilometers of canals have been constructed as part of the project.

The Chao Phraya Project had a major impact on agriculture in the lower central plain. Before the Project, transplanted rice was used in 22 percent of the fields; by 1990, over 70 percent of the farms were irrigated (Van Beek, 1995, p. 142). The project boosted land productivity, but not as much as predicted. There is some evidence that current levels of productivity are dropping. In 1970, according to the Royal Irrigation Department, the average harvest for naturally flooded land was 1750 kg/ha, while the average for irrigated land in the Chao Phraya Project area was 2940 kg/ha. In 1992, the yield for rainfed land remained the same, but the yield for irrigated land dropped to 2705 kg/ha (Van Beek, 1995, p. 142).

While the yields of transplanted varieties of rice are higher, the water needs are also higher than native varieties. The number of farmers switching to high-yield wet-season rice and the expansion in irrigated areas meant that by the 1980s, the project was unable to meet the demand for wet-season irrigation water. There is also an unmet demand for dry-season irrigation water. Technical limitations in the water distribution system prevent more than one-quarter of the lower basin from being used for dry-season rice cultivation (Van Beek, 1995, p.143).

4.5.4 Other Major Dams

In addition to the Chao Phraya Dam, several other major dams have been constructed in the basin. These dams were designed as multipurpose dams, providing both storage for irrigation and hydropower. Unlike the Chao Phraya Dam, they have no locks or provision for passage upstream. The Bhumibol Dam was built on the Ping River in the upper basin for both irrigation and hydropower generation. It was completed in 1964 with storage capacity of 13.46 billion m^3. Its height is 154 meters and its electricity generation capacity is 535,000 kilowatts (Van Beek, 1995, p. 140).

Completed in 1972, the Sirikit Dam was built on Nan River just above Uttaradit as a multipurpose dam. It has 9.51 billion m^3 of storage and 375,000 kW of generation capacity with an increase of 125,000 kW planned for 1995. The dam irrigates 284,000 ha in the Nan Valley during the rainy season and 48,000 ha in the dry season. It also allows the irrigation of an additional 400,000 ha in the lower Chao Phraya River basin (Van Beek, 1995, p. 140).

These dams were both built and originally operated under the supervision of the Royal Irrigation Department (RID). Now, however, they are operated by the Electricity Generation Authority of Thailand (EGAT) in consultation with the RID.

The Khiu Lom Dam was completed in 1981 on the Wang River just north of Lampang. It has a reservoir of 112 sq km and a generation capacity of 400 kW (Van Beek, 1995, p. 141). Two dams were built on tributaries of the Ping River north of Chiang Mai: the Mae Ngat completed in 1985 and the Mae Taeng completed in 1987. These dams were also designed for hydropower and flood control in addition to irrigation (Van Beek, 1995, p. 130).

As of 1993, the RID had four major dams planned for the North:

1. Sakae Krang River, a tributary entering the Chao Phraya River from the west between Phayauha Khiri and Manoram. Potential capacity is 1 BCM.
2. Yom River above Phrae. Potential capacity is 1.2 BCM.
3. Pasak River at Kaeng Khoi or Phattana Nikkom. Potential capacity is 1.5 BCM.
4. Nan River in Phitsanulok. Potential capacity is 1.3 BCM.

4.5.5 Hydropower

Thailand has many hydroelectric plants, but most electric power is produced by generating plants using natural gas and lignite. Only small amounts of petroleum are produced domestically, and most of the oil consumed in the country must be imported. Somewhat larger quantities of natural gas are recovered from the Gulf of Thailand and the northeast and contribute to national energy needs.

In 1989, Thailand had an installed hydropower capacity of 2,268 megawatts (MW). It generated 5,571 gigawatt-hours of hydropower which was 28.0 percent of the installed capacity (World Resources Institute, 1993, p. 331). EGAT has estimated Thailand's total hydropower potential, excluding international projects, to be 10,626.2 MW, over four times the present capacity. Expanding generation capacity on existing dams could expand production by 300 MW. EGAT proposes to construct six hydroelectric dams in order to raise installed capacity by 1,702 MW by the year 2003 (Van Beek, 1995, p. 193).

Concern about environmental problems relating to large dams have required that several projects be postponed. In previous projects, farmers who were relocated from fertile lowlands in planned reservoir locations to highlands with insufficient water supply for farming (Sabhasri and Wibulswas, 1992, p. 524). As an alternative to building new capacity, a demand management plan was adopted by the EGAT in 1993. It anticipates savings of 1,070 GWh annually through 1996 (Van Beek, 1995, p. 181).

4.6 Land Resources

4.6.1 Agriculture

Despite diversification of agricultural production, rice still covers over half the total land under cultivation in the country. Other major crops include rubber (in the Northeast region), maize (in the Central region), tapioca, sugarcane, pineapple and soybean (Economist, 1995, p. 18). In the past Thailand had ample land for expansion; however, population growth has been placing increasing pressures on the land.

Thailand rice yields are among the lowest in Asia. See Table 7. Historically, output of rice has been increased by clearing more land for cultivation. Now, however, there is little uncultivated land remaining which is suitable. Future increases in output will have to be achieved through more intensive cultivation. High-yielding rice varieties have already been accepted by Thai farmers; however, they did not adopt the cultivation practices required to achieve the high yield. The required practices include regulation of water-levels throughout the growing season, so one limiting factor is that the current irrigation system does not permit fine tuning. Upgrading the irrigation system will be necessary to increase yields (Van Beek, 1995, p. 191).

Table 7 Comparative Rice Yields, 1990 (kg/ha)

Country/Area	Yield
World average	3568
Asian average	3650
Japan	6325
China	5725
Indonesia	4318
Vietnam	3118
Philippines	2806
India	2693
Nepal	2306
Pakistan	2218
Thailand	1956
Cambodia	1331

Source: Van Beek, 1995, p. 191

4.6.2 Forests

Since 1970 the area of Thailand that is covered with forest has dwindled from about half to one-fourth. See Table 8. In the early part of this century, tropical rain forest covered over 70 percent of the country. Forest clearing for agriculture, excessive logging, and poor management are among the main causes of this decline. Less than one-fifth of the country is covered by grass, shrubs, or swamps, and the remainder is under settlement or cultivation. Where forests have been logged and not replanted, a secondary growth of grasses and shrubs has sprung up that often limits land use for farming.

Logging in Thailand was banned in 1989 as a response to a flood in November 1988 which killed 359 people and left hundreds more homeless. The watershed where the flood originated had been clear-cut for rubber plantations. The steep slopes were insufficiently stabilized leading to severe erosion. As a consequence, heavy rains produced a flood of mud which swept away a downstream village (Collins, 1991, p. 222).

The policy goal of the Thai government is to return the country to 40% forest cover, of which 15% would be natural forest and 25% production forest. Accordingly, a large-scale reforestation and watershed restoration program is underway. The Prime Minister's Office has initiated a program involving massive tree-planting in the upper reaches of the Ping, Wang, Yom and Nan Rivers. The program has encountered considerable opposition because it involves relocating nearly one million people, 90 percent of them tribal, from 3,500 villages which were illegally established in forest reserves. According to plans, more than 160,000 ha of forest will be planted by 1997 (Van Beek, 1995, p. 191).

Table 8 Amount of Forested Area

Year	Total Forest Area (km^2)	Percent Forest Area
1938	370,080	72
1947	359,800	70
1954	308,400	60
1961	272,420	53
1973	221,020	43
1976	195,320	38
1980	176,600	34
1983	167,990	33
1985	149,050	29
1990	135,000	26

Source: Collins (1991, p. 226); Onchan (1990, p. 48)

4.7 Interbasin Transfers

A number of interbasin transfer options have been considered in order to provide water for Bangkok's growing needs. The only project under construction is the West Bank Raw Water Project with a planned completion date of December 1996 (BMA/MIT, 1996, p. 95). This project involves the construction of a 106-kilometer canal to transfer water from the Mae Klong River at Vajiralongkorn Dam to a water treatment plant in Bangkok (Van Beek, 1995, p. 195).

Under consideration are schemes to divert water from the Mekong River or its tributaries into the Chao Phraya River basin. Also under consideration are transfers from the Mae Kok and Mae Ing to the Yom and Nan.

5. Institutional Framework

5.1 Principal Water Resources Agencies

There are approximately 30 department-level agencies involved in water resources management. National ministries have overlapping jurisdiction and often conflicting management objectives.

In the BMR, the government structure is split between water and wastewater management. The BMA Department of Drainage and Sewage is responsible for wastewater service through its Wastewater Treatment Division and flood control through its Drainage Division. The Metropolitan Waterworks Authority is responsible for the production and delivery of piped water in the BMA and the provinces of Nonthaburi and Samut Prakan. Neither agency has authority over groundwater use and pricing; these are governed by the Department of Mineral Resources.

The Provincial Waterworks Authority was created 1979 and is in charge of water supply outside of the BMR. It has rapidly grown to become the largest water supply agency after the MWA. The PWA has a staff of 5,000 which operate 210 water systems with 1989 gross revenue projected at 1.75 billion baht, or $70 million (Potter, 1994, p. 56). The creation of the PWA has resulted in some improvement in water management including increased connections rates and operational efficiency. The PWA has significant limits on its authority which may reduce its effectiveness. For instance, it cannot invest in projects, borrow or lend more than 5 million baht or enter into partnerships without Cabinet approval. More importantly, it is not allowed to set water rates for the water it provides.

The national Public Works Department has also been involved in water resources development (Potter, 1993, p. 59). Its current main responsibility is providing technical assistance to local governments on wastewater management. The municipalities are ultimately responsible for their own sewerage systems. The engineering staff at the Department is quite small and has difficulty supporting all the local governments.

The National Environmental Board (NEB) is a major environmental policy-making body. It was formed by the Improvement and Conservation of National Environmental Quality Act of 1975 (Potter, 1993, p. 57). It is chaired by the Prime Minister and composed of heads of government offices, such as the Ministry of Science, Technology and Environment and the Budget Bureau, and prominent members of the private sector (Macro Consultants, 1993, p. 9-9). The NEB provides guidance to the government and provides coordination among different agencies on environmental issues, but has no operating or enforcement authority. It can also recommend environmental standards for adoption by other agencies.

There are three agencies under the Ministry of Science, Technology and Environment which have duties relating to the environment. They are the Office of Environmental Policy and Planning, the Pollution Control Department and the Environmental Quality Promotion Department. These agencies are all newly created; formerly all tasks were performed by the Office of the National Environmental Board.

The Royal Irrigation Department (RID) is the largest and single most important agency in water resources management. It was established in 1903 as the Klong Department. As Thailand has become more industrialized, RID's traditional responsibility of governing irrigation has expanded into the construction of hydropower facilities, multi-purpose dams, and other water resource development activities. RID is a major supplier of raw water for water supply systems particularly for Bangkok. Only industrial consumers are charged for raw water. Others including MWA, other urban suppliers, and agricultural users do not pay for RID water.

The Department of Mineral Resources (DMR), within the Ministry of Industry, manages groundwater resources through its Groundwater Division pursuant to the Groundwater Act of 1977, amended 1985. Its responsibilities include issuing guidelines and permits for well installation, charging fees for groundwater use, surveying groundwater resources, preventing groundwater contamination and providing technical assistance (Potter, 1993, p. 57).

The Department of Industrial Works is also within the Ministry of Industry. It is responsible for the regulation of industrial wastewater and other industrial wastes (Macro Consultants, 1993, p. 9-12). The Department sets industrial effluent standards and enforces those standards. It is also constructing industrial waste treatment plants in the BMR.

The Department of Health in the Ministry of Health is responsible for establishing water use standards which protect public health. Enforcement of these standards is the responsibility of local governments. The effectiveness of the health standards has been minimal due to lack of trained enforcement staff and minimal sanctions for violations (Potter, 1993, p. 58).

The Electricity Generation Authority of Thailand (EGAT) is responsible for the construction and operation of hydropower plants. EGAT took over this responsibility from the RID in 1969 (Arbhabhirama, 1988, p. 111). The National Energy Administration and the Provincial Electricity Authority has also been involved in carrying out small hydropower projects with capacities of less than 6 megawatts.

5.2 Water Resource Planning

5.2.1 National Water Resources Planning

The National Water Resources Planning Board, which is under the National Economic and Social Development Board, is charged with national planning. Apparently, the Water Resources Planning Board has little power and is not able to effectively steer the direction of water management is the country. The RID and EGAT seem to be much more powerful. As described below, these two agencies determine the allocation of water in the Chao Phraya Basin.

5.2.2 Chao Phraya Water Allocation

Real-time water management is used in the Chao Phraya Basin in order to allocate dry-season supplies and to ensure a minimum flow at the head of the delta to control salt-water intrusion. The system has been operated by the RID with coordination with EGAT since 1980 (Frederiksen, 1993, p. 75). A simulation model of hydropower generation and water flows which was developed in 1977 is a major tool used to guide operation. The two main dams, the Bhumibol and the Sirikit, are operated by EGAT according to a weekly demand schedule prepared by RID. Local supplies upstream of the Chao Phraya Dam and rainfall in the basin are balanced against demands for power, irrigation, water supply, salt-water intrusion control and navigation. Shortfalls in the current week are made up in the following week.

Before each dry season, a dry-season cropping plan is approved by an interdepartmental committee chaired by the Minister of Agriculture. The plan gives priority to areas that could not be cultivated or were damaged in the prior wet season. In principle, the remaining dry season supplies are rotated from year-to-year equitably among different areas subject to the requirements of other users. Not all demands are met due to overcommitment. For example, releases for navigation have been consistently below the levels required to use some existing facilities.

5.3 Legal Framework

5.3.1 Water Law

Currently, there is no comprehensive water law in Thailand; instead, there are thirty-eight different laws relating directly or indirectly to water management (Srivardhana, 1994, p. 142). The most basic of these is the Civil and Commercial Code, which specifies the general principles of property rights and ownership. Since water is provided by nature, it does not belong to any person or party, and so the Civil and Commercial Code recognizes water as being under government control to be used for the maximum benefit of society. At the same time, individual landowners or users have the right to use water on or beneath their land. There are some articles in the Code, however, that prohibit excessive withdrawal of water that would harm other users.

There are two main laws which deal with irrigation (Srivardhana, 1994, p. 143). The first, the Royal Irrigation Act of 1942, gives the Royal Irrigation Department (RID) authority over water management within the proclaimed irrigation area that makes up approximately 20 percent of Thailand's arable land. The second, the People's Irrigation Act of 1939, governs the use of irrigation water in other areas. Of the two, the People's Irrigation Act is much less broad in scope although it applies to more areas of the country. It elaborates on the water rights specified in the Civil and Commercial Code by allowing only reasonable uses of water. Withdrawal for irrigation cannot be excessive and runoff must be returned to natural streams for reuse.

In the areas covered by the Royal Irrigation Act, the Royal Irrigation Department is given responsibility for managing water for the maximum benefit of society. The original Act was designed to promote agriculture, flood protection and navigation; amendments brought hydropower generation, industrial uses and public health also under the law's scope. Thus, under the law, the RID has almost total control of water management in designated areas. In practice, however, the RID must cooperate with other government agencies. For example, the Greater Chao Phraya Project is a designated irrigation area. The RID must coordinate its water management duties with the Electricity Generation Authority of Thailand (EGAT) and the Bangkok Metropolitan Authority among others.

The Royal Irrigation Act also gives the RID the responsibility to maintain irrigation works and eliminate wasteful water uses. The Minister of Agriculture is authorized to set charges for irrigation service or water withdrawn for other purposes within the areas covered by the Act. The irrigation charge is limited, however, to a maximum of 5 baht/rai per year. Although there have been many attempts, irrigation service charges have not been imposed. Charges for water withdrawn for non-agricultural uses are limited to 5 baht/m^3. These charges have been applied to industrial users and water supply authorities.

The use of groundwater is governed by the Groundwater Act of 1977. This Act gives the government control over groundwater development and management in designated areas. Currently, the only designated area is the BMR (Arbhabhirama, 1988, p. 122). The Act requires that a permit be obtained from the Department of Mineral Resources before drilling a well or extracting groundwater in a designated area. In addition, groundwater users in a designated area must pay for the groundwater extracted at a price close to that of locally available surface water supply. Groundwater extracted for domestic or agricultural uses in areas outside of water supply service areas are exempted from these water use fees as long as the extractions do not exceed 25 m^3/day. Permits are required in all cases; withdrawal of water without a permit can result in a sentence of up to 6 months in jail and/or a fine of 20,000 baht. The Groundwater Act also set standards for well construction, well abandonment and recharge of groundwater aquifers. The maximum penalty for not following these standards is 20,000 baht.

Other relevant laws are the Public Health Act and the Industrial Work Act. The Public Health Act prohibits discharging of waste and wastewater into public waterways. Violators are subject to a maximum fine of 50 baht ($2) (Srivardhana, 1994, p. 147). The Industrial Work Act regulates the activities at industrial plants, including wastewater treatment and disposal. In order to receive a permit to build or operate a plant, an appropriate wastewater treatment plan must be approved by the Department of Industrial Works. The maximum penalty is 100,000 baht for building a plant without a permit and 1 month in jail and/or 10,000 baht for failing to follow an approved wastewater treatment plan.

There are three draft laws under consideration which would provide a comprehensive water law. The first would give the government the authority to determine who will receive water rights. In a water crisis, the government would issues tradable permits which would allow farmers to sell their water rights to urban and industrial users. The second bill makes water the property of the state requiring the use of tradable permits at all times. It would also require the creation of a system of tradable permits for wastewater discharges. The third bill creates a water ministry with the power to assign water rights (Fairclough, 1994). These options are analyzed in more detail by Chatchom (1994).

5.3.2 Land Rights

The system of land rights in Thailand is currently quite complex because of its incremental development and that authority over land is split among several different government agencies. The development of the current legal framework of land rights is described by Feder et al. (1988). Traditionally, all land in Thailand belonged to the king; however, any Thai citizen could claim land in order to support his family. Until recently, there were few restrictions on land use including forest clearing, cultivation, or settlement. The rights to use land were by custom and not formally recorded. There was some registration of land ownership for tax collection purposes, but not for land right enforcement.

Until the first half of the nineteenth century land was abundant while labor was scarce. Consequently, power was organized not around large land ownership, but control of manpower through various patron-client relationships. This was the corvee system of labor which quite commonly a form of slavery. Large public projects required the import of large numbers of hired Chinese laborers, since the local labor force was insufficient. During this period slaves, not land, provided collateral for loans.

With the opening of the country to international trade in the second half of the century, there was a transition to property rights in land. Partially due to the commercialization of rice production, this lead to the issuance of the first title documents for rice land. Since the record keeping was not centralized, the system did not work well. Multiple claims and land disputes became more common. Eventually, in 1901 the government adopted a land titling system modeled after the Australian system with cadastral surveys and central land record offices. Land titling efforts during this period were concentrated in the Central Plain. There were no changes in the system until a comprehensive land code was passed in 1954.

The Land Code of 1954 is the basis for the current system of land rights. It establishes the powers and duties of the Department of Lands (DOL) for the allocation of land. The DOL issues land registration documents for all land that is not government property, that is, all land excluding forest reserves, national parks, and so on. There are three types of land documents issued by the DOL which grant secure ownership rights: the NS-4, NS-3 and NS-3K. The NS-4 is the only unrestricted title deed, but the other documents are in practice equivalent. There are also other documents which certify land use but do not grant ownership of land. Feder et al. (1988, p. 16) reports that only 12 percent of private land is covered by full title documents and only 53 percent is documented at all.

As described previously, land was abundant in Thailand and increases in agricultural productivity was achieved by expanding the amount of land under cultivation. Since Thailand was at one time almost completely covered by forest, expansion of agricultural land meant clearing forest land. This expansion was actively encouraged by the government and lead to substantial deforestation. Concern over this situation lead to the National Forest Reserve Act of 1964 which designated various areas as gazetted forest reserves and placed limits on use of these areas (Feder et al., 1988, p. 17). Agriculture was specifically prohibited. The Royal Forestry Department is responsible for carrying out the Act which originally covered 50 percent of the country.

There has been very limited success in protecting the forest from additional encroachment. Currently, an estimated 5.3 million hectares, or about one-fifth of the land designated as forest reserve, is permanently occupied and under cultivation by squatters (Feder et al., 1988, p. 17). Although many of these squatters have had possession of the land for over twenty years, they cannot obtain legal title to it. Some of these areas were already settled when they were declared to be forest reserves. Since 1981, the Royal Forestry Department has issued usufruct certificates to squatters which provide "temporary cultivation rights" (Feder et al., 1988, p. 18). These are called STK certificates and are limited to holdings less than 2.4 hectares. They cannot be converted to title deeds or transferred to other persons except by inheritance.

Several analysts have called for land tenure reform (Feder et al., 1988; Panayotou et al., 1990). The benefits of having secure title to land are well known. Title deeds protect landowners from land disputes and more importantly allow them access to institutional credit. This allows landowners to make investments to improve their land and protect it from degradation.

6. Potential Applications of Integrated Water Resources Management

6.1 Introduction

The preceding sections described the issues of water resources management in Thailand. Unmet demands for water are rising and water conflicts are increasing. The situation cannot be dealt with by focusing on one water user or one issue at a time. For example, the problem of flooding in Bangkok is exacerbated by excessive groundwater withdrawal. But excessive groundwater pumping is in part a result of the lack of public water supply and efficient pricing. The water available for supply is limited by the withdrawal of water for agriculture. All of these problems are related, so solving them requires a more integrated approach, one that considers the system as a whole. The goal is a water and resource management system which facilitates growth and development by using scarce resources as efficiently as possible, while explicitly recognizing the interactions of relevant environmental and social systems. Given the many interacting water resources issues in the Chao Phraya Basin and in Thailand as a whole, a more integrated water management system would be beneficial.

This section examines some of the ways integrated management could be applied in Thailand. It begins by looking at the institutional framework and making recommendations for reform which will facilitate integrated planning and management. Next, ways to improve integrated planning at the national, river basin and regional levels are presented. This is followed by an analysis of reallocation and supply and demand management. Then, recommendations to improve land and forest management are presented. Finally, the issue of human resources development is considered.

6.2 Institutional Reform

Frederiksen et al. (1993, p. xix) describes institutional reform as "at once the central problem in Asian countries and one of the most difficult." This is undoubtedly true for Thailand. Institutional reform is in many cases also a precondition to the success of other reforms in water management. Its importance is growing as growing demand and reduced prospects for increasing supply put more strains on overwhelmed institutions. This section discusses how the institutional framework in Thailand might be improved to facilitate better water management.

A comprehensive water code is needed that consistently addresses legal issues relating to water management. As mentioned above, several water bills are under consideration. They all appear to focus on the creation of a means of reallocating water among sectors through the use of tradable permits. A system of tradable permits could be an efficient way of allocating water, but since the trades are voluntary, the users who have most of the water under the present system (farmers) may be reluctant to give up their water. It is recommended that a water law be passed as soon as possible which contains sufficient incentives for farmers that reallocation from agriculture takes place. A more specific proposal about how the reallocation system should work is given below in Section 6.4.1.

The new water legislation should also address groundwater rights and use more comprehensively. Currently, the Groundwater Act applies only in the BMR, although the use of groundwater in other areas is expanding. It would be better to develop a legal framework now before groundwater conflicts become more serious. At the very least, the reporting requirements and construction standards aspects of the Groundwater Act should be extended to other areas of Thailand. This will provide valuable information for use in water planning and help prevent degradation of the resource. It is recommended that a doctrine of groundwater rights be included in the new water legislation and that the reporting and construction standards of the existing Groundwater Act be applied to all of Thailand.

The administrative structure relating to water resources of Thailand is in particular need of reform. There are too many agencies involved in water resources management with overlapping responsibilities. Eliminating or consolidating some of the agencies is probably the best option. If this is not politically feasible, then the responsibilities and jurisdiction of each agency should be redefined to eliminate overlap as much as possible. For example, the Department of Mineral Resources (DMR) should not determine groundwater prices; that should be the responsibility of the appropriate water supplier—the Metropolitan Waterworks Authority or the Provincial Waterworks Authority. The DMR should focus on mapping and monitoring of groundwater resources.

For high-level coordination, a national water resources planning agency with more authority than the current National Water Resources Planning Board (NWRB) is needed. Good integrated water planning is essential to Thailand's economic growth and development. To perform that planning, the national water planning agency should have access to the necessary resources. These resources include data collected by other agencies and a well-trained interdisciplinary staff. For this planning to be useful, the planning agency must have some authority to ensure the planning is implemented. It is recommended that the NWRB be expanded and given more political power. This could be accomplished by, for example, the appointment of a chairman who is well-respected in the water resources community and being given the authority to require reports from water resources agencies detailing progress toward the goals laid out in the national water plan.

A central repository of water and other natural resources data would facilitate effective planning on both national and smaller scales. One agency should be given the responsibility for data collection and dissemination. In addition to making essential data more readily available, it would tend to eliminate duplicative data collection and to encourage compatible data collection methods. This agency should use a geographic information system (GIS) to organize its spatial data on all natural resources. This will allow, for example, water and land resources information to be used together for more effective planning. It is recommended that an environmental data center be established with modern GIS equipment and a trained staff. Administrative rules should be established requiring all agencies collecting relevant data to provide digital versions to the data center. In exchange, the data center staff would prepare integrated data sets and maps and make them available to the agencies.

Institutional reform should also encourage decentralization of water service provision. Although national planning is most effective if done by the central government, provision of local water services is done better by small local entities. The government must provide a regulatory framework and enforcement, but is then relieved of the administrative burden of day-to-day operations. For urban water supply and sanitation, a utility form has been found to work very well by many countries. The MWA is already similar in form to a utility, but this should be expanded by giving the MWA (and the PWA) more power to set water rates. This utility form should be extended to the sanitation sector by making the sanitation division of the Bangkok Department of Drainage and Sewerage more autonomous and giving it authority similar to the MWA.

For the irrigation sector, a promising possibility for decentralization is to build on the long tradition of *muang faai* community irrigation systems. This social structure, if modernized, could provide an effective means of managing the agricultural use of water on a watershed scale. The community could charge irrigation fees which would both encourage more efficient use of water and provide funds to improve and maintain the irrigation system. The RID should encourage irrigation water users groups by giving them more responsibility over day-to-day operations. The RID should move toward an assistance and oversight role.

6.3 Water Resources Planning

6.3.1 National Water Plan

A stronger national water plan is needed which would state the goals, objectives and policies to guide water, land and related resource management. It would describe the current demand and supply of water in the different river basins, including groundwater and interbasin transfers. Particular attention would have to be paid to international agreements concerning the Mekong River. The national plan could be built on similarly structured river basin plans, described in the following section. Forecasts would be provided for a long time horizon—50 years is recommended by Frederiksen (1993). The national water plan would ideally be a component of the national social and economic development plan. This would address the issues raised by overlap between the water plan with, for example, the energy plan in the planning of hydroelectric power generation.

The effect of the water sector investments on the national economy could be assessed through the use of a water-macroeconomic model, such as the one described by Rogers, Hurst and Harshadeep (1993). This would facilitate the analysis of tradeoffs between water investments and investments in other sectors. This type of analysis would also provide some information on the multiple benefits of some investments. For example, reforestation would yield benefits in both the forestry and water resources sectors.

The national plan should lay out the structure under which intersectoral transfers of water would take place. National planning should also address the land and forest degradation as these are both linked to water resources. Improvements in land use by agriculture could allow more water to be used by other sectors and reduce water pollution from agricultural runoff. Reforestation and protection of upland watersheds would improve water quality and reduce flood runoff. Other Asia countries are moving toward the use of nation water plans and could perhaps be used as models. Perhaps the most systematic approach has been taken in China where river basin plans have been consolidated into a national water plan that in principle guides all resource management issues (Frederiksen, 1993, p. 54).

The next National Social and Economic Development Plan should include a major section on water resources management. This section should begin by laying out the principles under which water resources planning will take place in Thailand. These should include the use of integrated planning and management, the use of pricing and decentralization in water services, consideration of social and environmental impacts in the evaluation of water projects, and increasing community and water users involvement in water planning. Accomplishments and goals for institutional reform should be presented. Finally, the plan should give projections for water demand and supply and a description of measures which will be needed to balance them.

6.3.2 River Basin Plan

The river basin water resources plan has a content that is similar to the national water plan, but with more detail on specific projects and programs. It is updated on the same schedule as the national plan, which for Thailand is every five years. Another significant difference is that the river basin plan provides an opportunity for more participation by local entities and interested parties. This is particularly important in a large basin such as the Chao Phraya River Basin which has many conflicting interests which must be balanced. The basin plan might also contain the basic principles of a real-time operation plan, although the detailed operation plan would be updated more frequently by the operating authority.

Thailand has produced a number of individual basin plans, usually with the help of consultants (Frederiksen, 1993, p. 59). Although the plans have influenced project selection, they have seldom been institutionalized or systematically updated. This is probably due to the lack of a clear national framework which emphasizes basin planning. Since the basin plans are typically prepared by foreign consulting firms, the plan preparation processes probably do not include input from the stakeholders in the basin or give sufficient consideration to institutional issues.

A new basin plan for the Chao Phraya should be developed by the RID. It should provide a clear description of how the many interacting projects will be operated in a coordinated manner. All major stakeholders and interested parties should be invited to participate. Presentations by major agencies, water users groups and non-governmental organizations will provide input into the plan. The process of forming the plan will provide an opportunity to educate the water users about the basin and their role in it. The RID should coordinate the preparation of the plan and the formation of a river basin committee with representatives of stakeholder groups.

The river basin plan for the Chao Phraya should include planned future supply projects. Cost-benefit analysis should be applied to potential new projects. Care should be taken to incorporate social and environmental concerns into the analysis. As demonstrated by recent protests against new dams, the Thai people have many concerns about the effect of new water supply projects on the environment and their own well-being (Brandon and Ramankutty, 1993, p. 151). Thailand has requirements for the preparation of environmental impact assessments. Rules should be established which require that the impact assessments are made available to the public for comments and are given due weight in the decision process.

A numerical river basin model is essential to analyzing the effects of potential projects, designing new projects and developing operating plans for all projects. A number of modeling approaches exist. These can be divided into two broad classes: optimization models and simulation models. Optimization models, also called mathematical programming, use techniques such as linear programming, dynamic programming and non-linear programming to find the optimal set of decisions (Yeh, 1985). The decisions are optimal in the sense of maximizing an objective function while meeting a given set of constraints. In order to make optimization models tractable, significant abstractions or simplifications must be made. If the system is complex and there is a need for detailed model outputs, then a simulation model may be more appropriate.

Optimization models are usually used as screening tools to select the most promising location or sizes of new projects. Then, more in-depth analysis of the system is done with a simulation model. These models can be used to predict the effects of different schemes, but do not provide an optimal solution. Many river basin simulation models have been developed. Perhaps the most well-known are the HEC models developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center. The HEC-3 model simulates multi-reservoir systems with a monthly time-step. The HEC-5 model is more sophisticated and can accommodate a daily time-step (McMahon, 1993, p. 27.19). A newer version, HEC-5Q, simulates water quality parameters in addition to parameters simulated by previous versions (i.e., flood control, hydropower, diversions, and instream flows) (Willey et al., 1996).

A simulation model developed by Acres International Consulting Engineering has been used in the Chao Phraya Basin (Tingsanchali, 1995). The model was calibrated using data from 1976-1978, so it is probably considerably out of date considering the extensive developments and land-use changes which have occurred since then. This model should be updated to a more sophisticated model using current data.

There is a excellent opportunity to improve monsoon prediction and river basin modeling through international collaboration. An extensive study of the Chao Phraya Basin is part of the GEWEX Asian Monsoon Experiment (GAME). It is being conducted as part of the Global Energy and Water Cycle Experiment (GEWEX) initiated in 1988 by the World Climate Research Programme (WCRP) to observe and model the hydrologic cycle and energy fluxes in the atmosphere, at the land surface, and in the upper oceans. The goals of GAME are studying interannual precipitation variation on rice yield and improving the accuracy of seasonal predictions of precipitation (Japan Subcommittee, 1996). One particularly useful output of this study for Thailand is that water balance studies and hydrologic modeling of the Chao Phraya Basin and several smaller watersheds will be conducted. A considerable amount of data collection will also be involved including extensive remote sensing and the installation and monitoring of twenty additional rain gauges throughout the basin.

6.3.3 Regional Plan

Regional plans should also be used in areas such as the BMR where more focused planning is required. The Bangkok Master Plan (BMA/MIT, 1996) provides an example of an integrated regional plan which considers how to guide development of the BMR. This type of planning is an essential component to integrated water management because it provides of way of encouraging development in ways that put the least pressure on strained water and land resources. The Bangkok Plan should be adopted and similar plans prepared in other urban areas.

6.4 Balancing Water Demand and Supply

6.4.1 Reallocation

The agricultural sector uses over 90 percent of the water withdrawn in Thailand. There is an increasing need to reallocate this water for urban and industrial uses, which have much higher values than irrigation. The demand for nonagricultural water is projected to quadruple over the next 15 to 20 years (Sethaputra et al., 1990, p. 81). As the country develops, we expect the rural population to move to the cities thus perhaps freeing up water previously used for irrigation for other uses. However, most migrants to cities originate from rainfed agricultural areas instead of irrigated agricultural areas (Sethaputra et al., 1990). Even though the nonagricultural sector would be willing to pay farmers for water, there is no mechanism for such transfers to take place. This is also true for transfers of water between lower-value irrigated agriculture (rice paddy) and higher-value irrigated agriculture.

Both agricultural and nonagricultural users could use water more efficiently. Possible ways to encourage this through demand management are described below. The urban areas and industrial and service sectors are rapidly growing and will require a higher water allocation to ensure that water does not become a constraint to growth. Most of the additional water required will have to be reallocated from the agricultural sector. However, another important consideration is the effect these transfers will have on poor farmers. If the water is reallocated without compensating the rural poor, the rural-urban income gap will grow leading to a potentially undesirable distribution of income and unbalanced growth.

Under the present system, the RID has responsibility for operating the water management system on the Chao Phraya. Seasonal allocation decisions are made by a committee chaired by the minister of agriculture. It seems unlikely that the present institutional structure will be able to facilitate the reallocation of water use to a more economically efficient allocation. Thus, in this area in particular, institutional reform is essential to improved management. There has been some progress in right direction, however, as the water bills under consideration would use tradable permits to facilitate water transfers. The details of these bills are not known, but the idea of tradable permits has promise.

One way the system could work, described by Sethaputra et al. (1990), is to give all farmers capacity shares or permits in public irrigation systems and reservoirs regardless of whether their land is currently irrigated or rainfed. The physical amount of water the share actually represented would depend on the amount of water in storage at the end of that year's wet season. After the storage amount was announced each year by the RID, the farmer use his share in one of the following ways: use the water himself, sell it to another farmer, or sell it to a water utility. The more the demand for nonagricultural water increased, the more the MWA and other buyers would be willing to pay for it. The RID could act as intermediary between water buyers and farmers. To make the scheme simpler and to reduce transactions costs, the shares could be distributed to organized groups of farmers.

The benefits of this sort of reallocation system are potentially quite large. Water is efficiently reallocated to urban and industrial water users to satisfy their rapidly growing demand. The economic growth generated by these sectors would not be limited by water scarcity. At the same time, the agricultural sector would be able to enjoy some of the benefits of this growth. Perhaps in exchange for this additional income to farmers from water trading, some of the more distorting crop subsidies could be eliminated. By giving a value to the water used by farmers, there would be an incentive to improve irrigation efficiency.

6.4.2 Water Supply Management

Supply management has been the predominate approach used in Thailand thus far. This approach, which focuses on finding and exploiting additional water supplies to meet demand, is appropriate when there is ample water available. However, when demand grows enough so that water becomes scarce, water conflicts arise. At this point, it is worthwhile to in engage in both supply and demand management. This section deals with supply management, while demand management is described in the following section.

As a country develops and water use becomes more intensive, supply management must increasingly consider the effects of water supply on the environmental and the socioeconomic systems. This means that the impacts of new projects should be carefully examined as part of the project evaluation process. For example, the construction of a new dam might entail population relocation and habitat destruction—effects which should be considered as significant costs in the evaluation of a project. It is also important to consult the population which will be affected by the supply project. Most projects will not be effective without public participation, both because public input can improve a project and because, in a democratic society, projects will not be implemented without public approval. Public participation should be required as part of project evaluation.

An attractive option for increasing supply in the Chao Phraya Basin is importing water from nearby basins. These options should be examined carefully both in terms of how they fit into the national water strategy and their impact on the environment. In particular, there will impacts on seawater intrusion and ecology of the downstream and coastal areas in both basins. Analysis of these effects should take place before more large-scale interbasin transfers are initiated.

Since the Chao Phraya Basin is fairly well developed, the available locations for new dams are more limited and new projects will have high financial, environmental and political costs. This suggests that effort would be more effectively spent on improving the operation of the current system of reservoirs and other projects. The development of operating plans in the basin is complex because they must consider multiple objectives including flood control, hydropower, irrigation, water supply, instream flows and water quality. A numerical model is again an essential tool. Operating plans should be redesigned based on analyses performed using the enhanced and updated river basin model.

Since most areas of Thailand have extensive groundwater resources, these could be used to supplement surface water supplies. Conjunctive use is the coordinated and efficient use of both surface and groundwaters. A conjunctive use management system could be very effective in Thailand because of the large difference in precipitation between the wet and dry seasons. This system would recharge groundwater during the wet season and draw down groundwater levels during the dry season, thus using the groundwater aquifer for water storage. The situation in Bangkok is not an example of conjunctive use because the groundwater levels are never restored. The Department of Mineral Resources or the RID should investigate the conjunctive use of groundwater in agricultural areas.

6.4.3 Water Demand Management

Demand management is a management system which is designed to encourage efficient use of water (Sethaputra et al., 1990, p. 75). The most important component of demand management is water pricing. At least two studies have examined water resources pricing in Thailand. Potter (1994) focused on wastewater service and groundwater use in the BMR, while Sethaputra et al. (1990) considered ways to meet the water demands of the industrial and urban sectors. The recommendations of these two studies are incorporated into the discussion below.

Water in Thailand is currently underpriced in every sector, which leads to inefficient use and increasing pressure on supplies. The financial and environmental costs due to this inefficient use is borne by all taxpayers and not just the users of the resource—these costs are externalities which should be eliminated. Effective water pricing can lead to the following benefits: more efficient water use, reduced infrastructure costs for water supply and wastewater treatment, decreased environmental pressures, better water allocation, increased revenues to fund water supply and wastewater treatment, and more equitable sharing of costs.

In addition to water pricing, demand management includes other supporting activities. These include education programs to increase public knowledge of water conservation techniques and benefits, research to improve water efficiency, and implementing water-saving strategies such as water audits and reducing water losses. These activities can be implemented together with pricing to reduce water demand. For instance, average irrigation efficiency in Thailand is less than 30 percent as compared to 50 percent achieved in Malaysia, Taiwan and China (Sethaputra et al., 1990, p. 2). There should educational programs to encourage more efficient use of irrigation water.

The highest priority for water pricing reform is the BMR because this is the area of highest demand conflict. The following recommendations apply to all urban areas, however. The rates for piped water should be set to reflect the marginal cost of supply with the exception that the price of the first block of water should not be raised from present rates in order to protect low-income users. The marginal cost calculation should include opportunity cost, production cost and environmental cost. The prices should be indexed in order keep up with inflation and increasing water scarcity. Once treatment plants are operating, the same principles should apply to wastewater treatment pricing.

The MWA and PWA should be given more freedom by the central government to set water rates. The cabinet could perhaps maintain control over the initial block rates in order to protect the poor and small businesses. The water supply agencies should also be allowed to set groundwater rates instead of the DMR, which should instead focus on mapping and monitoring of groundwater resources. The MWA should be much better able to collect groundwater use fees because of its experience collecting piped water fees. The Department of Drainage and Sewerage might want to contract with the MWA for rate collection services to take advantage of this experience and to avoid administrative duplication.

Groundwater rates should be set to make them at least comparable to piped water rates. A current problem is that the industrial sector is pumping much more groundwater than it is reporting. In order to collect water-use fees for this unreported water, a system of presumptive use rates should be introduced. Factories would be required to account for their water use at a level corresponding to their production capacity and type of industry. A factory reporting water use per unit of output significantly less than the average for that type of industry would be charged the average price. The factory is presumed to be using groundwater unless it can document unusual efficiency through an independent environmental audit. This system of presumptive pricing could be used as a transition to one based on actual use.

There would be no effort to restrict groundwater usage other than through pricing. Many industries use groundwater because it is more reliable and of higher quality than public supplies or in some cases because no public supply is available. As the service of the MWA improves and expands, more users will switch to the public supply. The transition to the new system must be done in stages as a sudden increase in piped water rates would lead to a large increase in groundwater use. According to Sethaputra et al. (1990), industrial competitiveness would not be affected because the cost of water is a very small percentage of industrial operating costs.

6.5 Land and Forest Management

As described above, the forest cover in Thailand rapidly decreased from over 70 percent to about 25 percent. Concern over this problem led to a logging ban and other restrictions. These measures were enacted based on the assumption that logging caused the excessive deforestation. As explained by Panayotou and Parasuk (1990), while large trees were initially cut down by loggers, villagers followed the loggers' trails and cleared the remaining trees to make more farmland. Between 1960 and 1990, agricultural population increased by 14 million, while at the same time 90 million rai of forest were cleared. Deforestation is now largely a problem of the poor looking for land to farm. In 1990, there were an estimated 8 million forest encroachers—people residing illegally in national forest reserves, although many moved into the forest before it was declared a reserve.

Panayotou and Parasuk (1990) performed an econometric analysis to determine the demand for agricultural land and thus the pressure for deforestation. The study concludes that the demand for cultivated land "will decline in the future due to: (1) labor migration to the industrial and service sectors, (2) slower population growth, (3) a shift from land-using crops to land-saving crops, (4) stagnating crop prices, and (5) higher productivity" (Panayotou and Parasuk, 1990, p. 3). Unfortunately, the portion of existing farmland that is unused is expected to increase, so landless farmers will still have to clear forest to make new farmland. Each rai of forest which is cleared is estimated to create a net social loss of 150 baht. This is an underestimate because the calculation only includes the effects of flooding, erosion, landslides and other deforestation effects on agricultural productivity.

The study concludes with several recommendations which reflect the integrated analysis of the land and forest situation. First, they recommend redrawing the reserve forest boundaries to better reflect social, economic and environmental factors. Areas which are permanently encroached should be degazetted and the actual forest areas should be protected more effectively. Reforestation of watershed areas should be conducted if public investment criteria are met. An official unambiguous forest reserve map should be prepared and forest protection policies should be clearly defined.

Second, they recommend giving secure land title documents to occupants outside the redrawn forest reserve boundary. Currently, inhabitants of areas inside forest reserves are not legally able to obtain title documents even though they may have inhabited that land before it was declared a forest reserve. Without the security of ownership, landholders neglect investment which will improve or maintain soil quality or increase productivity (Feder et al., 1988). Increasing land productivity will help alleviate poverty and decrease further forest encroachment.

Third, a progressive land tax should be introduced to encourage land distribution and full utilization of land. Current low, non-progressive land taxes encourage land ownership concentration which is known to increase the amount of unused land. A higher, more progressive land tax would encourage the sale or rental of unused land, thus reducing the pressure to clear forests to obtain land. This measure will encourage an increase in the supply of available agricultural land.

The forth recommendation focuses on reducing the demand for land by facilitating the migration of labor from the agricultural sector to a nonagricultural sector. This migration could be encouraged by improving education in the villages and eliminating physical capital subsidies to industry. Education expands the available job opportunities for villagers, and the elimination of subsidies increases the demand for labor in industry. The final recommendation is to consider eliminating agricultural subsidies. This would increase the efficiency of farm operations and reduce the incentives of working in the agricultural sector.

This analysis provides a good example of an integrated approach. The seemingly more direct approach taken by the Thai government of simply moving people off of encroached land is not likely to be effective because it does not consider the underlying reasons for encroachment.

6.6 Human Resources Development

Another important ingredient in effective water management is the existence of a government staff with the necessary skills and training. This depends on the existence of educational institutions which are designed to provide this training. Building the capacity of Thailand's higher educational system in environmental science, engineering and management will be required to meet current and future needs. Excessive reliance on foreign consultants in large scale water management is not likely to be successful because the solutions to most water problems require the involvement of water users and an intimate understanding of local conditions.

The extensive training of Thais abroad has also been criticized as ineffective. Ludwig and Gunaratnam (1994), for example, are skeptical that the ambitious sewerage project in Bangkok will be successful. They claim that the system design was chosen to maximize the use of sophisticated hardware and that the operational success of such plants in Thailand in the past has been poor. The reason is that Thailand has very little experience in this complex field. While many Thais are educated abroad at prestigious universities, this academic training does not provide the experience necessary to operate complex engineering systems, such as large-scale sewerage facilities. In addition, the training they do receive relates to high-cost Western approaches which may not be appropriate for developing countries.

Graduate programs in water resources and hydrology should be built at Thai universities. One way of doing this is to participate in international collaborations. The GAME collaboration is a particularly good opportunity to develop hydrology research programs; Thai universities should participate as much as possible. Other collaborative opportunities should also be investigated.

7. Conclusion

This thesis has examined the application of integrated water resources management in the Chao Phraya River Basin in Thailand. It began by outlining the formidable challenges of water management and how the interconnected nature of water resources issues suggests an integrated management approach. Although implementation of integrated management throughout the world has not been extensive, there is a growing consensus that it is needed to respond to many water resources problems. These problems are growing more severe and complex because of the increasing pressure on resources of population growth and economic development.

Few places illustrate this point better than Thailand, with one of the world's fastest growing economies and the resulting rapidly growing water conflicts. The Chao Phraya Basin is the site of most of these conflicts as it contains both the country's extensive irrigated fields and Bangkok, a soon-to-be mega-city. A detailed description was provided of the major water and related resource issues and of the current institutional framework. These descriptions made apparent the many connections among the issues and the relative lack of connections among the corresponding institutions. Thus, the potential benefits of integrated management became clear.

The final section provided recommendations on how to realize these benefits. Institutional reform—including establishing a comprehensive water law and forming a more rational administrative structure—is essential. Improved water planning on the national, river basin and regional levels is needed. The tools of demand management, particularly water service pricing, should be used more extensively. Land and forest management must also be considered due to their significant effect on water issues. Finally, human resources development is the key to future success in managing water resources effectively.

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