CHAPTER 2

CHANGES IN GROUNDWATER MANAGEMENT TO ENHANCE SUSTAINABILITY OF WATER RESOURCES IN ASIAN CITIES
- Recommendations from SWMP -

As one of the outputs of the three-year research, we formulated recommendations for making groundwater management in Asian cities better in order to enhance sustainability of water resources. The recommendations are divided into two types: Recommendations for Sustainable Groundwater Management in Asian Cities and Recommendations for Each SWMP Case Study City.

The first type of recommendations addresses the common concerns on groundwater management shared by many Asian cities. The recommendations are further divided into two categories, namely, "key recommendations" and "recommendations on other concerns". The key recommendations are intended to address the common and critical issues of groundwater management identified through the research. The second type of recommendations deals with other concerns on groundwater management which were identified at the series of dialogues with relevant stakeholders in these case study cities. When these recommendations are put into practice, they should be interpreted and optimised in accordance with local contexts, such as the local hydro-geological, social, economic and cultural conditions.

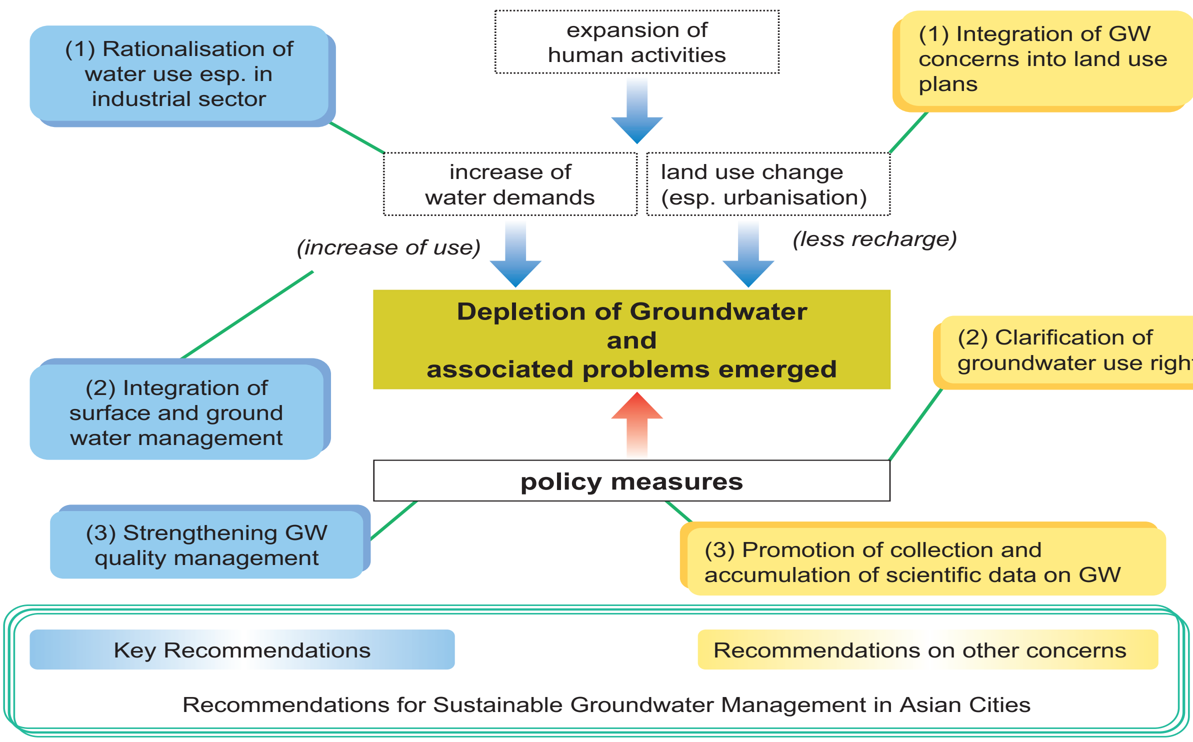

Figure 1. Categorization of Proposed Recommendations

1. Recommendations for Sustainable Groundwater Management in Asian Cities

1.1. Key Recommendations

Recommendation 1
Rationalisation of water use should be prioritised in urban water management. In particular, more governmental resources should be allocated for the promotion of rational water use by the industrial sector, which is a large user of groundwater.

As we saw in Bangkok, Bandung, and Osaka and Tokyo in the 1950s and 60s, intensive use of groundwater by the industrial sector was a major cause of depletion of the resource, which is often associated with other environment problems such as salt water intrusion and land subsidence. To mitigate such problems, governmental policy tried to limit groundwater use by the industrial sector. Industries provide an important basis for economic and social activities, and therefore it is often difficult to enforce reduction of industrial groundwater use without provision of other reliable sources of water as alternatives to groundwater.

On the other hand, providing surface water supply to act as an alternative to groundwater use is not feasible in many cases, such as in Bandung, because surface water resources available are too limited to be an alternative source of groundwater. Even if there is potential for surface water capacity, development of a new water supply infrastructure needs significant financial resources and is often associated with risk to the local environment. In such cases **priority should be given to measures to promote rational use, such as water reclamation and reuse and conjunctive use of different water sources including surface, ground and reclaimed water.**

In promoting the rationalisation of water use in industries, the following elements should be addressed.

i. **Coordination with ministries and agencies engaged in different aspects of industrial water use should be facilitated.** Water use by the industrial sector, especially in industrial parks, is often under the jurisdiction of industrial ministries. Promotion of water recycling is also often conducted by industrial ministries. On the other hand, public water supply is a matter for water-related agencies and conservation of water resources may come under the remit of environmental ministries. Coordinating between different organisations' policies also helps minimise transaction costs in implementation of relevant policy measures.

ii. **Economic incentives/disincentives to promote rational use of water should be provided to change water use practices in industries.** Such economic instruments include (i) increase of water charges including a groundwater user charge, (ii) introduction of a wastewater discharge fee, and (iii) financial support during the initial stages of introduction of relevant technologies.

iii. **Stringent enforcement of water quality standards would help to motivate the rational use of water.** Stringent water quality standards and/or strengthened enforcement of such standards may increase the cost of wastewater treatment. Industries could be persuaded to use water rationally in order to avoid the costs of introducing upgraded water treatment systems to meet more stringent standards. Efforts to minimise freshwater supplies would also be undertaken to increase efficiency of wastewater treatment.

iv. **Technical guidelines and quality standards for reclaimed water use and conjunctive use ought to be prepared by governments for different types of users and intended purposes.** Proper guidelines and quality standards are crucial in order to minimise potential risks to human health, goods, and also the environment. The quality of water required differs between beneficial uses and intended purposes. Therefore, different guidelines and standards should be set.

v. **Awareness on the part of the industrial sector of potential benefits of water reclamation and reuse should be promoted** through technical training and water recycling programmes as we saw in the Bandung case study. Such benefits include; reliable quantity and quality of reclaimed water, economic benefits brought by reduction of the cost of freshwater supplies as well as wastewater treatment, and diminished environmental impacts.

Recommendation 2
Management policy on groundwater should be integrated with that on surface water and other sources of water. This integration will enable more efficient and sustainable use of available water sources.

Some successes in groundwater control in case studies show that the provision of surface water as an alternative to groundwater is a very important factor in the success of groundwater use controls. Examples include the inter-basin transfer projects in Tianjin, extension of piped water supply in Bangkok, and Industrial Water Supply Works in Japan. As the successes show, groundwater management is very closely linked with management policy on other water sources. However, even in the success cases, groundwater is often managed independently or there are discrepancies in the views water use as a whole. To promote efficient use of the limited water resources, it is necessary to integrate groundwater management policy with management policy of other water sources. To promote integration, the following aspects should be considered.

i. **An integrated water plan needs to be formulated for effective management.** If such an integrated plan exists, the common goals of water management will be clarified and shared among relevant stakeholders. Practical measures to address discrepancies among current management measures on different water sources should be included in such a plan.

ii. **Organisational arrangements should be reinforced by clarifying the responsibilities of each organisation and setting mechanisms for policy coordination for different water sources.** Proper organisational arrangements could promote integrative planning and management. Such integrative approaches not only optimise management costs, but are also very useful in minimising risks by diversifying sources of water.

iii. **Surface water quality controls should be promoted in terms of groundwater conservation.** In many Asian cities, including Tianjin, Bandung, Colombo and Ho Chi Minh City, surface water is highly contaminated as a result of improper discharge of untreated wastewater and solid wastes from households and industry. Such contamination of surface water may result in groundwater pollution. Surface water quality controls should be further promoted in the context of preventing potential pollution of groundwater in Asian cities.

Recommendation 3
Groundwater quality management should be strengthened to secure the safe use of the groundwater.

Groundwater is still used as an important resource for drinking purposes in Asian cities. In some cities people can drink groundwater without treatment if it is not artificially polluted. We observed that our case study cities suffer from specific pollution, such as naturally occurring pollutants (e.g., fluorine), salinisation due to sea water intrusion, and coliform contamination caused by improperly treated domestic wastewater. Due to this contamination, groundwater can not be used for drinking without treatment.

Not only is the treatment of domestic and industrial wastewater and hazardous solid waste very poor, but also fertiliser and pesticides are used in agricultural activity in the case study cities. In addition, because rapid urbanisation and intensive agriculture may accelerate further in the future, new types of pollutants such as heavy metals, VOCs, and pesticides which have not been serious problems or monitored so far might represent future risks to groundwater.

Although there are laws and regulations on groundwater quality management which address the traditional types of groundwater pollution, the implementation of these laws and regulations is quite weak in the case study cites. In addition, groundwater quality management systems for new types of pollutants have not been established yet.

Therefore, groundwater quality management should be strengthened for the sustainable use of safe groundwater in consideration of the following points.

i. **Groundwater quality monitoring systems should be established or strengthened in order to support the active use of groundwater.** Especially, information on water quality issues relating to emerging pollutants (such as VOCs) should be collected.

ii. Based on the appropriate monitoring data on water quality and identified pollution sources, **water quality standards should be designed to fit the local conditions of water quality and policy direction.** In addition, different quality requirements for different beneficial uses should also be set up to promote the effective use of water resources.

iii. Because both the increase in contaminants and the diversity of pollutants are likely to affect Asian cities in the future due to rapid industrialisation and intensive agricultural activity, **innovative pollution controls, especially for groundwater conservation, should be implemented in order to reduce the increased risk of groundwater contamination.** Reduction of discharged wastewater through wastewater reuse/recycling which can reduce the groundwater contamination risk should be implemented as a first step. New technologies available should be fully utilised.

1.2. Recommendations on Other Concerns

Recommendation 4
Land use plans should integrate groundwater concerns to maintain sustainability of the resource.

Urbanisation is a typical phenomenon observed throughout the Asian region and the accompanying land usage changes can alter the natural setting of the area in many ways. Water resources are heavily exploited and the land surface is completely distorted and changed into denuded, cultivated, or paved areas. These changes often reduce the recharging capacity of groundwater, thereby increasing and accelerating surface runoff. Despite there being such a close link between land use and groundwater conservation, land use plans often fail to include concerns for groundwater conservation. In practice, the following actions should be considered.

i. **Recharging zones should be protected against uncontrolled development to maintain the recharging capacity of groundwater, and such concerns should be included in a land use plan.** Conservation of forest areas in upper stream zones may contribute to maintaining groundwater recharging capacity.

ii. Artificial recharging of aquifers is useful in maintaining the sustainability of groundwater quantity in areas where groundwater stress is very high. **In recharging groundwater, however, due consideration should be paid so as not to degrade the original quality of groundwater. Guidelines on water quality for recharging should be set, considering both the original quality and the required quality for beneficial use.**

iii. **Locations of landfill sites and industries,** especially those which use potentially hazardous materials such as chemicals/heavy metals, **should be carefully considered so as not to affect the quality of groundwater.** If groundwater is used especially for potable use, the area where recharging and water intake take place should be protected.

iv. Public awareness is a key issue to promote recharging of groundwater. **Decentralised recharging schemes in households or communities can contribute to the public awareness.** Rainwater harvesting in areas with enough precipitation is also effective for groundwater recharge. For example, installation of rainwater harvesting facilities can be mandated or encouraged in building codes as a source of water for non-potable domestic use or recharging.

Recommendation 5
Groundwater abstraction/use rights should be granted to groundwater users under government controls. These rights systems should be clarified in statutory forms in the relevant laws.

Groundwater abstraction/use rights sometimes hinder the effective planning and implementation of groundwater management especially in countries where groundwater is widely recognised as private property such as Sri Lanka and Japan. For example, there was a debate in Japan in the 1950s on whether groundwater use could be regulated by laws and regulations. As people became aware of the problem of land subsidence as a result of intensive groundwater use, government restrictions on groundwater became viable for the sake of public welfare. However, it is still difficult to impose charges on groundwater users in Japan partly because the right to use groundwater still remains private.

In the initial stage of groundwater use, there are often no regulations or control of groundwater use and therefore individual groundwater users can abstract groundwater in their private lots as much as they want until the groundwater dries up. For sustainable use of groundwater there must be rules that all groundwater users need to follow, in most cases this will be in the form of laws and regulations. Charging for groundwater use is a way to rationalise water use, but an effective charging system should be supported by clear ideas of who has the rights to abstract and use groundwater and to what extent. Groundwater use rights are very important as a basis for the introduction and implementation of measures to control use of groundwater as a common good that people shall share. Therefore, **it is better to define the abstraction/use rights in statutory form and clarify the roles of government as a sound basis for groundwater management policy planning and implementation.**

Recommendation 6
Collection and accumulation of scientific data on groundwater should be promoted as the basis for sound groundwater management.

The current scientific information on groundwater to support groundwater management is either very limited or not well accumulated. In order to overcome the situation and promote effective groundwater management, the following actions are recommended.

i. **Database systems pertaining to groundwater should be established or upgraded to share reliable information with relevant stakeholders.** Basic facts such as geological formation, groundwater level and groundwater use should be included in the database. Currently, certain amounts of data on groundwater levels are often gathered in the region, but other facts such as how groundwater exists and how much groundwater is used are poorly stored.

ii. In most cases, financial resource for data collection and accumulation are limited. To use such limited resources effectively, **collecting data on the quality and quantity of groundwater should be prioritised giving due consideration to the local situation and policy objectives of each city.** In addition to the governmental sector, universities could play a role in the collection and analysis of data and information for policy making as neutrals in Asian cities.

iii. **In order to increase financial resources to establish a database system, using part of the revenue from groundwater charges should be considered.** A new charging system introduced in Bangkok and some cities in Japan is one option.

iv. **The definitions of technical terms are very important in promoting sound discussion and common understanding of accumulated data.** Precise definitions of terms are crucial, especially in the international context. Controversial terms include safe yield and sustainable yield. The terms should be defined based on reliable scientific data relevant stakeholders can agree on.

2. Summary of Recommendations for Each Case Study City

Recommendations specifically aimed at each case study city were formulated by our research partners. Details of the recommendations are described in the respective case study summary reports in Chapter 3, but in this section there is an overview of the site-specific recommendations provided in the following table.

Table 1. Summary of Recommendations for Each Case Study City

Area of Recommendations	Bangkok	Bandung	HCMC	Tianjin	Sri Lanka
Legal/Institutional Framework					
Strengthening enforcement of regulations (including penalty systems)	+	+	+		+
Stricter limits on groundwater use	+ (for industry)	+		+	+ (except for individual use)
Coordination of existing organisations		+			+
Establishment of new authority to allocate GW	+				
Financial Tools					
Increase of charge for groundwater use	+	+	+		
Charging for agricultural groundwater use	+				
Improvement of charging system (from flat to progressive)	+				
Private sector involvement in groundwater charge collection		+			
Compensation scheme for conciliation of water conflict					+
Establishing a groundwater market	+				
Water Resource Management					
Integrated basin water resource management		+	+	+	+
Artificial recharge of aquifers	+	+	+		
Redefinition of the Critical Zone	+	+	+		+
Reduction of water loss/ enforcement of water saving			+		+
Water demand management	+				
Land Use					
Zoning		+			
Reallocation of industries	+	+	+		
Related to Alternative Water Resources					
Development of surface water including construction of artificial dams		+			
Implementation of water transmission				+	
Water supply scheme for industries	+	+			
Promotion of wastewater reuse		+	+	+	
Rainwater harvesting		+	+		+
Promotion of blackish water use				+	
Desalination of seawater				+	
Pollution Control					
Surface water pollution control					
Construction of wastewater treatment facilities		+	+	+	
Implementation of Polluters Pay Principle (PPP)	+				
Encouraging cleaner production (CP)		+	+		
Enhancement of pollution controls in the agricultural sector			+		
Introduction of new discharge standards					+
Scientific Data on Groundwater					
Improvement to groundwater monitoring	+	+		+	+
Improvement to database system	+				+
Further studies about groundwater management issues	+			+	+
Proper definition of safe drinking water					+
Others					
Encouraging public participation	+			+	+
Encouraging public awareness		+	+	+	+
Capacity building	+				

CHAPTER 3

SUMMARY OF CASE STUDIES

This chapter is the compilation of the summary reports of SWMP case study cities shown in the following figure. The reports presented the information and the facts are the basis of analysis and recommendations in the previous chapters.

Each case study consists of facts and figures relevant to groundwater resources and its management. The studies then focused on other water sources related to groundwater management in the respective studies. Lastly, the case study shows the recommendations specifically to the case study cities which were developed by the SWMP research partners. In the formulation of recommendations, stakeholder meetings were held in each city to hear more diverse view and ideas from the participants with differing backgrounds.

Figure . SWMP Case Study Cities

CHAPTER 3-1 Sustainable Groundwater Management in Bangkok

The research on Sustainable Water Management Policy (SWMP) initiated by the Institute for Global Environmental Strategies (IGES) aims to propose integrated policy options for sustainable water resources management in urban and peri-urban areas of Asia with a focus on groundwater resources. Case studies that provide synopses of water resources management and use practices in several areas in the region were conducted, and IGES has collaborated with the Water Engineering and Management (WEM) Field of Study of the Asian Institute of Technology (AIT) for performing the case study for Bangkok, Thailand. The Bangkok Case Study aims to obtain an overview of water resources use and management practices—particularly for groundwater resources—in Bangkok. The existing policies on groundwater management in Bangkok are analyzed and improvements needed in this direction are recommended.

1. The Study Area

The Case Study focuses on the groundwater resources management situation in the seven provinces of Bangkok, Nonthaburi, Samut Prakan, Pathumthani, Samut Sakhon, Nakhon Pathom, and Ayutthaya, which comprise the region considered as the economic and political center of Thailand, and where groundwater is most extensively exploited (figure 1).

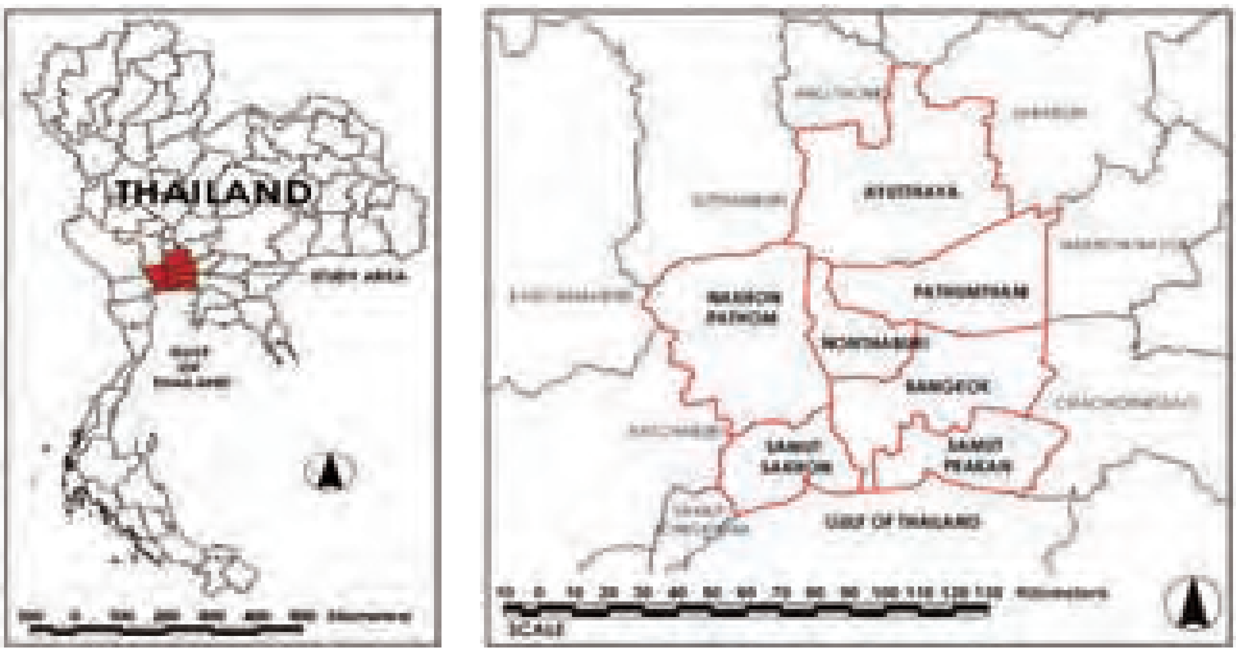

Figure 1. Thailand Case Study Area

Soft to stiff, dark gray to black clay, also known as "Bangkok Clay," ranging in thickness from 20–30 m makes up the topsoil layer of the Study Area. Beneath the Bangkok Clay layer are unconsolidated and semi-consolidated sediments intercalated by clay layers and containing large volumes of voids for water storage, which form several confined aquifers that are distinguished into eight layers as: (1) Bangkok Aquifer (50 m zone), (2) Phra Pradaeng Aquifer (100 m zone), (3) Nakhon Luang Aquifer (150 m zone), (4) Nonthaburi Aquifer (200 m zone), (5) Sam Kok Aquifer (300 m zone), (6) Phaya Thai Aquifer (350 m zone), (7) Thonburi Aquifer (450 m zone), and (8) Pak Nam Aquifer (550 m zone) (AIT, 1982).

The total population in the Study Area in 2003 was about 10.6 million. With a total land area of about 10,300 km^2, the average population density in the Study Area was about 1,000 persons/km^2 at that time. The population in Bangkok makes up more than half of the total population in the Study Area. The total Gross Provincial Product (GPP), or the value of all final goods and services produced within a province in a given year, in the Study Area in 2002 was 2,661,167 million baht (at current prices), which accounted for approximately half of the country's GDP, and 72% of which was generated in Bangkok.

The climate in the Study Area is humid and tropical. With rainfall amounts varying from 1,000 mm (in Pathumthani) to 1,300 mm (in Bangkok), the mean annual rainfall in the area is around 1,120 mm. The Study Area is situated in the southern part of the Lower Chao Phraya River Basin in Central Thailand, and comprises about 30% of the Basin, which is about 34,000 km^2 in area (Kasetsart University, 1998). In 1996, total water demand in the Lower Chao Phraya Basin was estimated at 17,500 million m^3/year consisting of 16,900 million m^3/year surface water and 600 million m^3/year groundwater. By 2016, it is estimated that this amount will increase to more than 18,000 million m^3/year, comprised of 17,400 million m^3/year of surface water demand and 800 million m^3/year of groundwater demand (RID, 2000).

2. State of Water Resources

A large portion of Thailand's water resources is used for agriculture. According to RID, the total amount of water used for irrigation in the Lower Chao Phraya Basin in 1996 was 12,747 million m^3, which was more that 70% of the total water demand in the basin at that time. RID further estimates that agricultural water use in the basin would slightly increase to 12,780 million m^3 in 2006 (RID, 2000). The second highest use for water in the country is for domestic consumption. RID estimates indicate that the domestic water consumption (surface and groundwater) of 2,362 million m^3/year in 1996 in the Lower Chao Phraya River basin will increase by about 9% in 2006 and 14% in 2016. Accounting for only 2% (or 1,312 million m^3) of estimated total water withdrawal in Thailand in 1993, the industrial sector is a relatively small user of water compared to the agricultural sector, which accounted for 92% (or 48,172 million m^3) of the country's water consumption in that same year. However, it is estimated that in the future water use for agriculture will level off while that for industrial use will continue to grow rapidly. According to estimates, industrial water use in the Lower Chao Phraya Basin (combined with water demand for tourism) amounted to about 1,097 million m^3/year in 1996, and that this will increase by about 22% to 1,335 million m^3/year by 2006 and by 34% to 1,469 million m^3/year in 2016 (RID, 2000).

The Metropolitan Waterworks Authority (MWA), and the Provincial Waterworks Authority (PWA) are the two main water supply service providers in Thailand. MWA supplies water to Bangkok, Nonthaburi, and Samut Prakan, while PWA is responsible for supplying water to the other remaining provinces in the country. The area of responsibility of MWA is around 3,200 km^2, and in 2003, MWA water supply service covered 1,515 km^2 of the area, with the number of connections reaching 1,540,203. Although only around 47% of the total area of responsibility was covered by MWA in 2003, the number of people served was approximately 89% of the total population in the area, which was about 7.8 million in 2003. Four of the seven provinces in the Study Area—Ayutthaya, Nakhon Pathom, Pathumthani, and Samut Sakhon—are part of PWA's area of responsibility. Available data from PWA show a rapid increase in water production and sales in Pathumthani, a moderate increase in Samut Sakhon, and slow increase in Nakhon Pathom and Ayutthaya. Service coverage has been low, especially for Nakhon Pathom and Ayutthaya, where statistics show that PWA supplies water to only about 2–3% of the population in these provinces. In Samut Sakhon, the percentage of residents receiving water services from the PWA has increased from 3% in 1997 to almost 6% in 2003. In Pathumthani, a larger portion of the population (11% in 1997 to 15% in 2003) compared to other provinces receives PWA water supply services.

3. Issues and Discussion on Groundwater Management

In Thailand, groundwater has primarily been developed for domestic and industrial purposes and used only as a supplement for surface water irrigation by the agricultural sector. However, in recent years a large number of agro-wells have been installed in the Study Area. Of the eight layers comprising the aquifer system in the Study Area, the second (Phra Pradaeng), third (Nakhon Luang), and fourth (Nonthaburi) layers from the ground surface are the most used because of their high productivity, accessibility, and the good quality of groundwater they produce. The deeper aquifers also contain groundwater of good quality but are not as popular for use because of their relatively great depths. However, exploitation of the deeper aquifers, especially for industrial use, has increased in recent years.

3.1 Groundwater Use and Associated Problems

Available records show that extensive use of groundwater in the area began in the mid-1950s, when it was primarily used to supplement surface water for public water supply. By 1976, it was estimated that groundwater pumpage in Bangkok and in the adjacent municipalities of Nonthaburi and Samut Prakan had increased to about 937,000 m^3/day from 8,360 m^3/day in 1954. In 1968, there was a major increase in the use of groundwater for public water supply, after which public usage became relatively constant at around 300,000 to 400,000 m^3/day. It reached its peak in the late 1970s and early 1980s, amounting to 464,000 m^3/day in 1980, and then slowly declining after earnest implementation of control measures in 1983. Because the expansion of piped-water supply services by waterworks agencies lag behind urban development, private usage of groundwater has generally continued to increase. The private sector is currently the most significant groundwater user in the Study Area (figure 2).

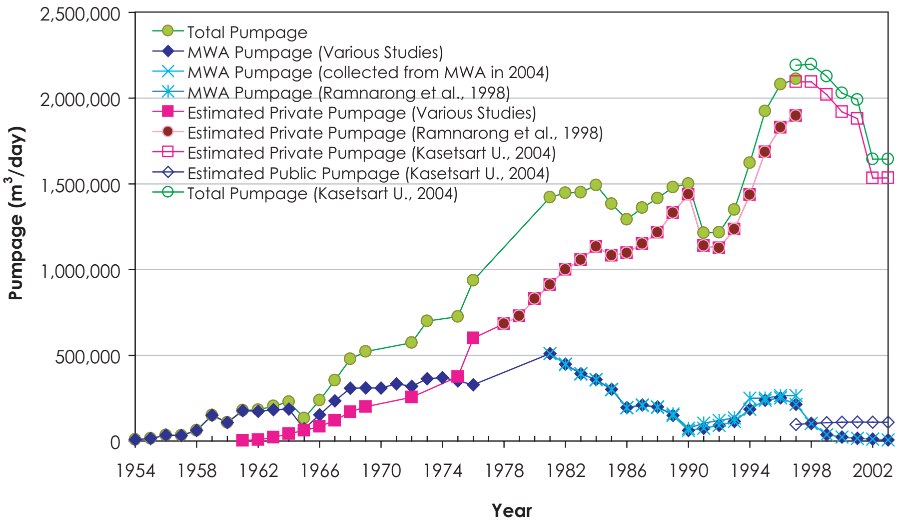

Figure 2. Groundwater Pumpage in Bangkok and Surrounding Areas
Source: AIT and DMR, 1978; Ramnarong et al., 1998; Kasetsart University, 2004

Recent estimates of groundwater use in the Study Area indicate that total pumpage by registered private wells has been around 2 million m^3/day since 1997, varying from 2.2 million m^3/day in 1997 to 2 million m^3/day in 2001, and decreasing to 1.7 million m^3/day in 2003. Groundwater use for public supply, which is composed of groundwater use not only by waterworks agencies but also by various other government agencies, was estimated at about 155,000 m^3/day from 1997 to 2003. In 2003, the total registered groundwater use in the seven provinces of Bangkok, Nonthaburi, Samut Prakan, Pathumthani, Nakhon Pathom, Samut Sakhon, and Ayutthaya was approximately 1.8 million m^3/day, 92% of which was by private users (Kasetsart University, 2004).

In Bangkok City and the surrounding provinces, excessive use of groundwater resources has caused serious environmental problems such as rapid groundwater depletion, quality deterioration, and land subsidence. Considerable lowering of the ground has occurred in many places, and observations from monitoring wells across the region indicate substantial declines in water levels in the aquifers (figure 3).

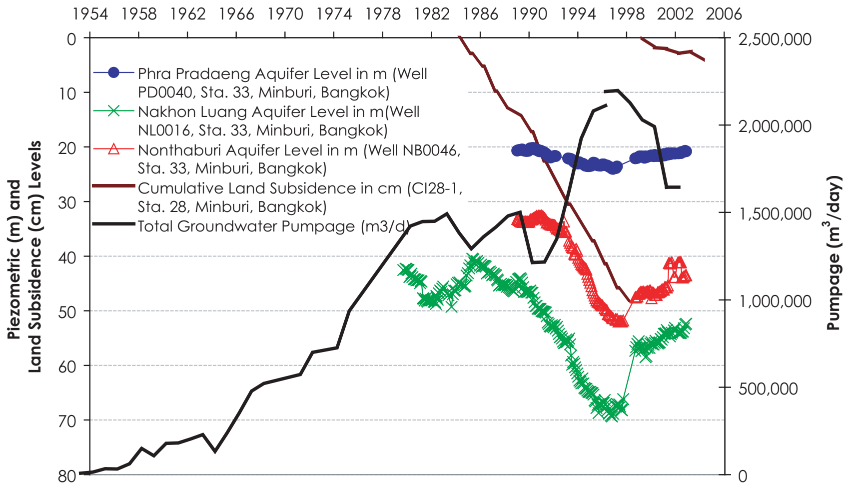

Figure 3. Total Groundwater Pumpage in Bangkok and Surrounding Areas, and Piezometric and Land Subsidence Level Variations in Minburi, Bangkok

Land subsidence has been a continuing problem in the Bangkok region for the past four decades, and the provinces comprising the Study Area have been identified by the Department of Groundwater Resources (DGR) as Critical Zones seriously affected by groundwater problems. The occurrence of land subsidence in the Study Area has been attributed to the extensive decline in groundwater levels, which in turn is due to excessive groundwater pumpage. In 1969, land subsidence was given widespread attention when many indications were being observed in the Bangkok area (AIT, 1982). Protrusions of well casings in Bangkok indicated around half a meter of land subsidence in central Bangkok in 1978 (figure 4) (AIT, 1981).

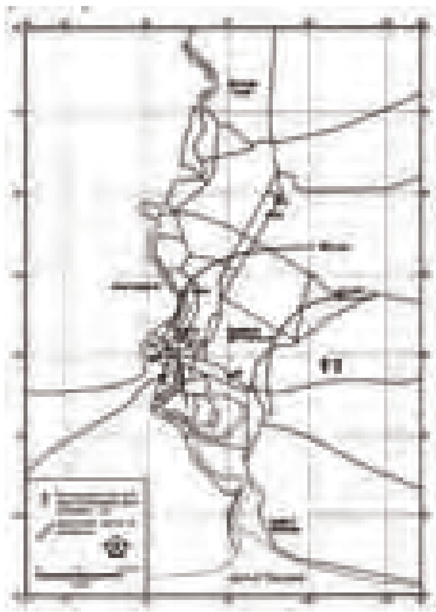

Figure 4. Subsidence in Bangkok from the First Leveling Survey by the RTSD in 1978
Source: AIT, 1981

An investigation program initiated by the National Environment Board (NEB) of Thailand in 1978–1981 showed irrefutable evidence of land subsidence due to deep well pumping in the Bangkok Area. It was found that subsidence rates varied from place to place, with the average rate of subsidence in Bangkok City at about 5 cm/year. Maximum subsidence rates of more than 10 cm/year were detected in the eastern part of Bangkok. Piezometric observations showed that the areas characterized by high subsidence rates also experienced great declines in groundwater levels, which dropped to a maximum of 40–50 m below the ground surface (AIT, 1981). Land subsidence continues to occur throughout the Bangkok Metropolitan Region, although at lesser magnitudes than before (figure 5). Subsidence rates of around 1 cm/year exist in most parts of the region. In the central, east, and southeastern parts of Bangkok City, where from 1978 to 1999 land subsidence was from half a meter to more than one meter, much improvement in the land subsidence problem has been observed in recent years. From 2001 to 2003, land subsidence in these areas has reduced to about 1 cm/year. Nevertheless, land subsidence is observed to be migrating to the outskirts of Bangkok City and into the surrounding provinces of Samut Prakan, Pathumthani, Nonthaburi, Samut Sakhon, and Nakhon Pathom. In the industrial province of Samut Prakan, land subsidence at rates of 2–5 cm/year was observed in 2003, as well as in Samut Sakhon located southwest of Bangkok (Kasetsart University, 2004).

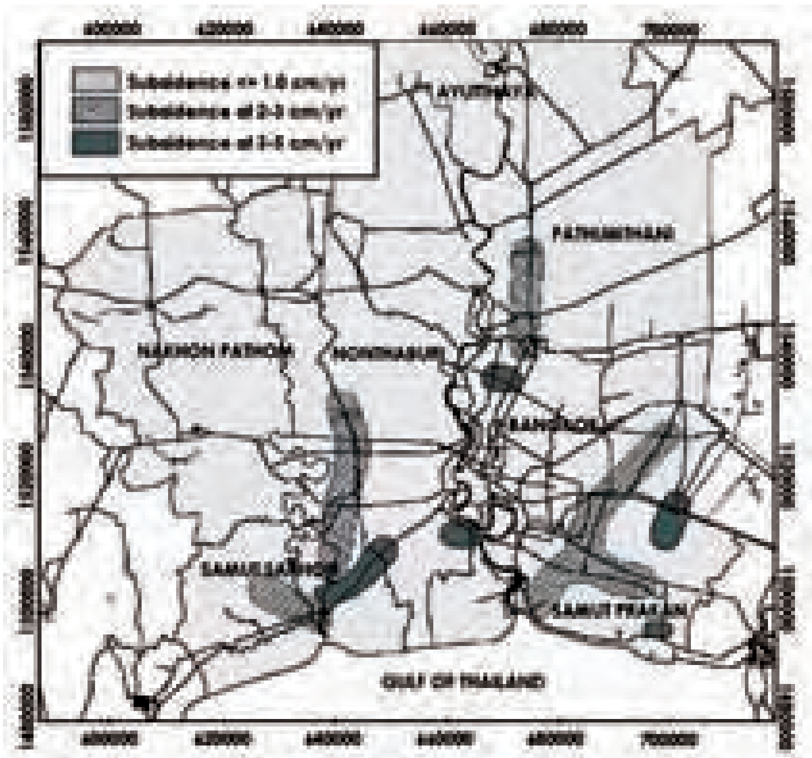

Figure 5. Map Showing Land Subsidence in 2003
Source: DGR 2005

Water levels in the Bangkok Aquifer System have been declining since the late 1960s due to increasing rates of extraction, with water levels in the aquifers dropping a total of more than 40 to 50 m. Groundwater drawdown started in central Bangkok in the late 1960s and then spread over the entire Bangkok Metropolis in the 1970s. With further increased pumping, piezometric levels in pumped aquifers declined. Records have shown that water levels went down about 5–10 m from the late 1970s to around the early 1980s. Some recovery was observed after strict enforcement of the regulations in 1983, after which water levels started to decline once again. Groundwater levels continued to decline until the late 1990s, especially in the Phra Pradaeng, Nakhon Luang, and Nonthaburi Aquifers. The lowest groundwater levels were reached in around 1997, recovering afterwards although not up to the previous levels of the late 1980s (figure 6). The increase in groundwater levels provide a positive sign on the recovery of groundwater, but further studies might be needed to determine the safe yield, based on the increasing or constant water levels attained. These studies should also consider the domain for defining the safe yield, whether it has to be localized or specified for every aquifer.

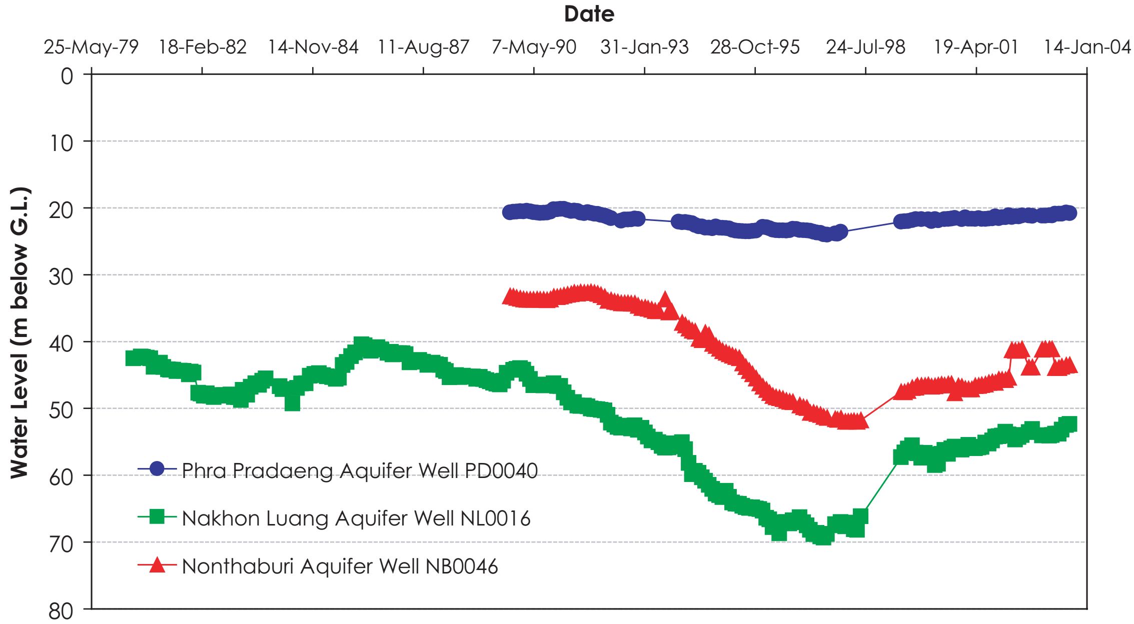

Figure 6. Groundwater Level Variation in Station 33: Minburi, Bangkok

As for groundwater quality, recent analysis of monitoring data from DGR has shown elevated concentrations of chloride (increased salinity) for the three most extensively used aquifers (Phra Pradaeng, Nakhon Luang, and Nonthaburi), especially in areas near the Gulf of Thailand in Samut Prakan province and along the Chao Phraya River (Kasetsart University, 2004).

3.2 Policy Responses and Future Challenges

Since the emergence of various problems associated with groundwater in the Study Area in the 1960s and 1970s the government has implemented numerous measures to mitigate these problems. These policies and regulations, which are of various types, include:

(1) Regulatory Measures

- *Comprehensive law for groundwater*. A specific law concerning groundwater in Thailand came about in 1977 when Groundwater Act, B.E. 2520 (1977) was enacted (JICA et al., 1999). The Act came into effect in 1978, and it has been amended twice: in 1992, and in 2003. It contains provisions for controlling the exploration and drilling for groundwater, the use of groundwater, the recharging of aquifers through wells, and the protection and conservation of groundwater resources in the country.
- *Designation of groundwater regions and critical zones*. To control groundwater use and mitigate environmental problems associated with it, areas most severely affected by groundwater-related problems such as land subsidence and groundwater depletion were designated as Critical Zones where more control over private and public groundwater activities was instituted.
- *Licensing for well-drilling and groundwater use*. Under the Groundwater Act, the government initiated licensing for the installation of wells and private groundwater use. Licenses were required to extract groundwater, and pumpage limits were instituted through these permits.
- *Groundwater use metering*. The installation of well meters was enforced in 1985 in support of the use charges that the government started to levy from private users at that time.
- *Establishment of groundwater quality standards*. To promote groundwater and environmental quality conservation, standards for groundwater for drinking purposes were established through the Groundwater Act and, in 2000, groundwater quality standards for the conservation of environmental quality were issued (PCD, 2004).

(2) Economic Measures

Implementation of Groundwater Use Charges: Groundwater Use Charges were first implemented in 1985 in the six provinces of Bangkok, Nonthaburi, Pathumthani, Ayutthaya, Samut Prakan, and in parts of Samut Sakhon, where 1.00 baht was charged for every cubic meter of groundwater used. By 1994, the charge was increased to 3.50 THB/m^3, and the government began to charge for groundwater use in the whole country. Between 2000 and 2003, the groundwater charge was gradually increased in the Critical Zone from 3.50 THB/m^3 (July 2000) to 8.50 THB/m^3 (April 2003).

Implementation of Preservation Charges: The Ministry of Natural Resources and Environment (MONRE), based on the 2003 amendment of the Groundwater Act, has recently imposed the Groundwater Preservation Charge for all groundwater users in the Critical Zone. Starting at 1.00 THB/m^3 (1 September 2004), the charge is set to increase to 8.50 THB/m^3 in 2006, leveling off at that rate beyond 1 July 2006. Because of the institution of the Charge, the total cost per cubic meter of groundwater used in the Critical Zone has become relatively high compared to the piped water charge, which has helped in limiting the exploitation of groundwater in the area. The total groundwater charge increased from 9.50 THB/m^3 in 2004, to 12.50 THB/m^3 by mid-2005, and to 17 THB/m^3 by July 2006 and beyond. In a perception survey, industries responded that they will continue the use of groundwater even if the charges are increased; the maximum rate acceptable to them being 20 THB/m^3 of water used.

Levying surcharges and penalizing violators of regulations: According to the Groundwater Act, anyone not following the regulations will be fined not more than 20,000 THB, and those who use groundwater in declared Critical Zones or without licenses will be imprisoned for not more than six months and/or fined 20,000 THB and the drilling machinery and equipment confiscated. Registered private users who fail to pay for their use of groundwater on time are also penalized.

(3) Supporting Measures

Groundwater monitoring system: The Bangkok Groundwater Monitoring Network was established under the comprehensive study programme on groundwater and land subsidence from 1978–1981, and it is used to collect data on groundwater levels, land subsidence, and groundwater quality in the various aquifers in the Study Area.

Groundwater database system: The Groundwater Database System was established in 1995 through the JICA study on "Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and its Vicinity" (JICA, 1995). The database aids in planning and decision making for improved groundwater management.

(4) Other Measures

Artificial recharge of aquifers: The government is also presently considering the implementation of technical measures to mitigate the problems due to groundwater overexploitation in the Study Area, including the artificial recharge of the depleted aquifers.

Public awareness programs: The DGR has launched public awareness programs to educate the population about the proper use of groundwater resources in the country through publication of various brochures and booklets.

Fifty years of groundwater management efforts in Thailand have seen the enforcement of a wide range of measures aimed at keeping groundwater exploitation in the country under control. Although many of them have resulted in the alleviation of groundwater problems, some have been found to be not as effective as expected. Various interrelated factors hinder effective implementation of these policies and measures. The effectiveness of the existing policy measures is described below:

Groundwater Well-Drilling and Use Licenses: A major barrier towards proper control over excessive and illegal use of groundwater resources in the Study Area is lack of institutional thrust from concerned authorities, resulting in ineffective implementation of laws and regulations. Despite the existence of laws requiring licenses for all private groundwater-related activities in the country, illegal private wells still exist. Shortage in the number of DGR Inspectors and budgetary constraints limit the authorities' abilities to ensure that all private well users are registered with DGR. Many groundwater wells remain un-metered even with the existence of a regulation requiring the installation of meters for wells more than 15 m deep. Although this regulation has allowed authorities to obtain more accurate quantification of groundwater use and has ensured that users pay for exactly how much they extract and are not exceeding allowable amounts, all registered users do not comply to this regulation. Even though the Groundwater Act has helped the authorities to gain some control over the groundwater activities, illegal pumping still exists. The shortage in the number of DGR inspectors for monitoring the wells and other budgetary constraints act as hindrances in ensuring that all the private groundwater wells are registered. The system for information dissemination is also not effective. Although ignorance of the law is never a good reason for not following it, some groundwater users are just truly uninformed of the regulations for using groundwater resources in the country.

Some inappropriate legislation may also be considered as a hindrance to effective implementation of regulatory measures. For instance, the legal definition of groundwater as being water occurring beneath the ground at depths exceeding 15, 20, or 30 m (depending on the region in the country), which still stands today even after two amendments of the Groundwater Act, keeps the use of groundwater from shallow aquifers all over the country largely unregulated.

Penalties and Fines for Violators: Punishment for lawbreakers range from a fine of not more than 20,000 THB to six months of imprisonment, and penalties are charged for late payment of groundwater charges, but the effectiveness of penalties and fines imposed upon violators of regulations has been limited, possibly due to the relatively meager fines and that inspections for discovering violations and enforcing the penalties are not conducted enough and may not be cost effective.

Establishment of a Groundwater Monitoring System: The Groundwater Database System has allowed convenient access, by groundwater managers and decision-makers, to groundwater resources-related information in the Bangkok Region necessary in assessing the status of the resource and formulating proper management measures and strategies. However, the full potential of the Groundwater Database System is currently not being realized due to lack of maintenance and updating. Budget constraints have also hindered the regular maintenance, rehabilitation, and expansion of the Groundwater Monitoring System, which has enabled the collection of important information about the aquifers as well as the land subsidence situation in Bangkok and surrounding provinces.

Control of Groundwater Use in Critical Zones: Limiting groundwater use in declared Critical Zones in 1983 was generally unsuccessful, sustained only in areas where alternative water sources were made available. Nevertheless, at present, groundwater pumping by MWA has been essentially curtailed, and estimates show a decreasing trend in private groundwater use since peaking at more than 2 million m^3/day in 1997.

Phase-Out of Groundwater Use for Public Water Supply by MWA: The earlier attempts of MWA to totally phase out use of groundwater for supplying water to its customers in 1983–1987 were unsuccessful. Nevertheless, the agency has continued to improve its distribution system, increase production capacity, and increase raw surface water abstraction and thus is successful in completely stopping the groundwater pumping for public water supply.

Groundwater Use Charge: The effectiveness of levying charges for groundwater use in controlling private groundwater abstraction has been limited. Without alternative sources of water, consumers have no choice but to continue using groundwater. Also, groundwater use charges are not levied for agricultural groundwater use.

Metering of Groundwater Wells: The effectiveness of this control measure has been limited by the fact that not all registered users conform to the regulation. Although groundwater users will have to pay for the full allowable amounts (even if they actually use less) when their wells are un-metered, this has not driven them to abide by the regulations, perhaps because the existing system of groundwater-use reporting by the consumers themselves, wherein well owners report their monthly use to the DGR, who in turn bills them for their consumption, does not really incite groundwater users to do so. The DGR has a policy of inspecting groundwater use for each registered well at least once every two months, but they are unable to do so because of a shortage of inspectors.

Groundwater Preservation Charges: Unlike the water user charge, there is a flat rate for the preservation charge. This has to be based on the different sectors, i.e. greater charges for those sectors using more groundwater.

With the introduction of new ideas and concepts such as effective resources use and integrated water resources management, the formerly supply-driven approach to groundwater resources development and management in Thailand has been shifting towards management based on scientific/academic knowledge. Project studies have been initiated and conducted in recent years as the responsible authorities (DGR) seek to better understand and learn more about the occurrence of groundwater resources and its associated problems in the country.

3.3 Proposed Policy Options for Sustainable Groundwater Use

Policy options which can mitigate the groundwater-related problems in the Study Area were drafted in the first stakeholders' meeting, conducted in July 2005. The proposed policy options were analyzed for their feasibility and effectiveness, and suitable paths for implementation—as well as implementing agencies—were identified in the second stakeholders' meeting conducted on April 2006. Suitable policy measures to resolve the issues on groundwater management in the Study Area, as developed in the two stakeholder meetings are as described below:

Firm implementation of regulations: Illegal use of groundwater may be curbed through institution of stiffer penalties and, at the same time, ensuring that proper mechanisms for enforcing these penalties are in place. Another approach would be to pardon currently unregistered groundwater users and ask them to register with DGR.

Stricter limits on industrial water/groundwater use: Reduction of water/groundwater use by industry may be advanced through provision of incentives for the recycling and reuse of water as well as the promotion of clean technologies. Safe yields need to be specified for different areas and suitable quotas need to be established for groundwater use in the industrial areas, within the safe yields. Further studies need to be conducted in this direction.

Relocation of large groundwater users, such as industries, outside the Critical Zone: A study was conducted to determine the technical, economic, and environmental feasibility of this approach, but it is difficult to implement. This measure needs financial incentives from the side of Government, to be implemented. Rather than relocating the existing industries, the new industries can be started outside the Critical Zone.

Establishment of an authority that will extract groundwater for water supply: Increased control over groundwater extraction without actually curtailing its use may be achieved through the establishment of an agency that will extract groundwater and supply water in the Study Area.

Further increase of Groundwater Use Charges: With the implementation of Groundwater Preservation Charges in the Study Area, total charges for groundwater have become more comparable with public water supply rates, such that the impact of further increasing groundwater use charges in terms of lessening groundwater use will now be more marked.

Charging for agricultural groundwater use: It was also suggested that agro-wells, which are currently exempted from paying Groundwater Use Charges, now be charged for groundwater use. Another alternative to this is to have a Ministerial Notification designating the depth of groundwater wells as 15 m below the ground, throughout the country.

Modifying Groundwater Preservation Charge rates: A flat rate for the Groundwater Preservation Charge is currently in place in the Study Area. It was suggested that a study be conducted to develop a progressive Groundwater Preservation Charge rate based on use amounts and the groundwater resources conditions in each area. In addition, groundwater stakeholders in the area should be better informed of the purposes and objectives of Groundwater Preservation Charges.

Implementation of Polluters Pay Principle (PPP): The Polluters Pay Principle, if implemented based on either the amount of wastewater produced or on the pollution load, could help in reducing the groundwater quality deterioration. The reduction in the amounts of wastewater will also result in more rational use of groundwater by industries.

Establishing a groundwater market: An efficient allocation of the depleting groundwater resource can be obtained by establishing formal markets, but requires appropriate infrastructure as well as legal and institutional arrangements.

Artificial recharge of aquifers: Increasing groundwater recharge through artificial and natural means to facilitate recovery of piezometric heads in the aquifers was also proposed. Although several projects have been conducted about the feasibility of artificial recharge in the Study Area, it is yet to be implemented by the DGR. Recharging water into aquifers through a system of wells will not only help increase piezometric levels, it will also assist in mitigating saline water intrusion by creating a freshwater barrier protecting the groundwater.

Encouraging public participation: The public must be made aware of the groundwater situation in their areas, and they must be given opportunities to actively participate in the development and enforcement of solutions to problems resulting from groundwater use.

Updating/redefinition of the Critical Zone: Updating of the Critical Zone in accordance with the master plans of the MWA and PWA must be considered for more reasonable and realistic implementation of mitigation and control measures in the Study Area.

Improving monitoring of groundwater activities: A good system for regular inspection and monitoring of groundwater wells in the area must be established. Regular inspections must be conducted to prevent illegal well drilling and the use of groundwater without the use of meters, and authorities must be firm at meting out punishments to violators. These targets may be achieved through the involvement of the private sector in groundwater use monitoring and charge collection. The industries themselves may also assist the authorities in establishing the telemetry system, which will help in monitoring abstraction by large users of groundwater.

Improving Groundwater Monitoring and Database systems using the Groundwater Development Fund (GDF): The GDF may be used to improve and maintain the groundwater monitoring and database systems, and for establishing a telemetry system. However, present regulations make it difficult for stakeholders and even the DGR to use the GDF.

Thus, the amendment of the Groundwater Act or relevant regulations regarding the use of the Groundwater Development Fund may be required. Regular data collection must be conducted to update and maintain the Groundwater Database System at the DGR. Data consistency must be ensured, and access to the database by groundwater managers and users alike must be improved. Links between stakeholders and authorities in terms of database use and information exchange must be established, and data exchange between provincial and central groundwater offices must be enhanced for regular updating of the database.

Development of alternative water sources: The Thai government may also develop alternative water sources to supply water to industries, which are the biggest users of groundwater in the Study Area.

Water demand management; Instead of further developing supplies, the authorities may promote water demand management, which involves the judicious and efficient use of water. Systematic use of the resources and/or the conjunctive use of groundwater and surface water may be promoted to minimize groundwater extraction.

Capacity-building for national and local groundwater managers: Local groundwater management capacities must be developed, possibly through seminars and training, because it is anticipated that groundwater use will continue to increase in the future, and that problems will continue to occur unless proper controls are implemented.

Conduct further studies about groundwater management issues: Further studies need to be initiated on measures such as artificial recharge of groundwater and on the safe yield aspects which can help in sustainable groundwater management.

Given the issues mentioned above, there is an increased need to consider the sustainability factor in the use and management of groundwater resources in the Study Area. This demands immediate measures to be taken to rationalize groundwater use, which has to be prioritized starting from the heavy users. The case study has identified the industrial sector as the major user of groundwater in the Study Area, with around 69% of the total groundwater use in the seven provinces. Considering the pace of industrial development, it is expected that there will be a corresponding increase in industrial groundwater use. Hence, immediate measures need to be taken to rationalize the amount of groundwater used by the industries. This is made possible only if alternate sources are made available to meet the water demand of the industries. The development of suitable alternative sources which can supply water to the heavy users of groundwater has also been identified as a suitable option for sustainable groundwater management by the stakeholders. Hence a study on alternative water resources was also conducted to consider its feasibility as a measure to rationalize groundwater use in industries.

4. Issues and Discussion on Alternative Water Resources

The study on alternative water resources focused only on three provinces due to time and data constraints. Bangkok, Nonthaburi and Samut Prakan provinces, which are being supplied by a piped water supply from MWA, were selected for this study. Water use in the Study Area as of 2003 is given in figure 7. The surface water supplied by the MWA accounts for about 90% of the total water use, consisting of 48% residential use, 51% non-residential use and 1% public supply and other uses. The non-residential use includes business, state enterprises, government agencies and industries. Groundwater use is constituted of 60.8% industrial use, 38.6% domestic use and a mere 0.2% agricultural use. Even if the amount of groundwater used is only 10% of the total water used in the three provinces, the effects of groundwater pumpage such as land subsidence and groundwater level decline is seriously felt in this area, which points to that fact that groundwater resources are still overexploited.

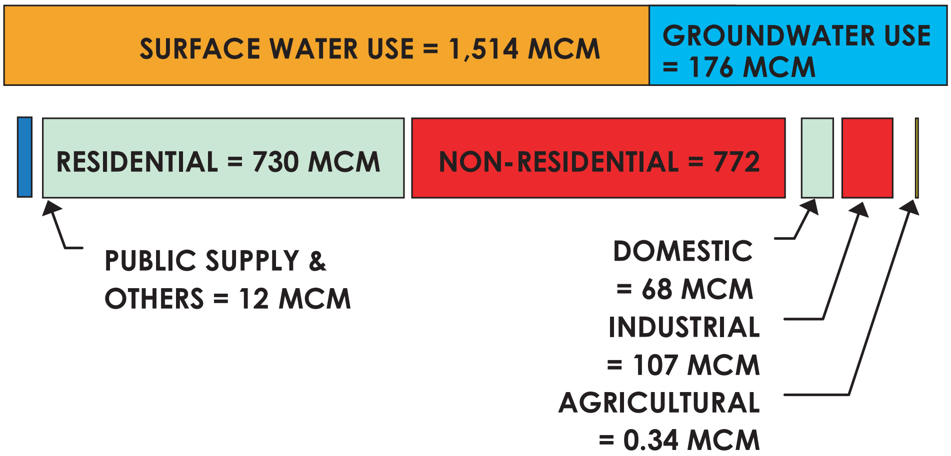

Figure 7. Current Water Use by Various Sectors in Bangkok, Nonthaburi and Samut Prakan, for the Year 2003

Note: MCM means million/m^3

As is the case for the seven provinces, the industrial sector is the largest user of groundwater in these three provinces as well, accounting for about 61% of the total groundwater use. Hence the study on alternative resources was focused on the industrial sector. The percentage of groundwater use in total use is further broken down for the three provinces in the Study Area as given in Table 1. 76% of the total water supplied by MWA is to Bangkok, and only 5% is supplied to Samut Prakan. This might be the reason for the higher percentage of groundwater use in Samut Prakan, when compared with the other two provinces. The actual percentage will still be higher considering the fact that there are a large number of shallow agro-wells which are not registered with the DGR, and also the groundwater pumpage given includes only the requested pumpage at the time of registration.

Table 1. Percentage of Groundwater Use in the Total Water Use by Three Provinces, for the Year 2003

Province	Total water use (million m^3)	Surface water use (million m^3)	Groundwater use (million m^3)	GW use in total water use (%)
Bangkok	1340.14	1289.84	50.30	3.75
Nonthaburi	160.81	130.32	30.49	18.96
Samut Prakan	188.30	93.54	94.76	50.30
Total	1689.25	1513.70	175.55	10.39

If this groundwater use needs to be reduced or brought to amounts which are not detrimental to the environment, the most significant option to be considered is the provision of other alternatives from which the water demand of the particular sectors can be satisfied. At the stakeholders' meetings conducted in July 2005 and April 2006, the stakeholders recommended the development of alternative water sources for industries. The alternative options identified as a result of stakeholder dialogue included expanding the piped water supply by the MWA and PWA, promoting wastewater reuse and recycling in industries, and establishing an industrial waterworks authority with the sole purpose of supplying water to the industries. However, the option of having an independent industrial waterworks authority might not be economically feasible in the Thai context, so the study focused on only two alternatives: expansion of piped water supply and promoting wastewater reuse and recycling.

For the study on alternative water sources for industries, it is important to analyze the present situation of groundwater use by industry and also the reasons for industrial preference of groundwater. To obtain primary information on industrial groundwater use and their level of adoption of the proposed alternative sources, a perception survey was conducted. A stakeholders' meeting with a particular focus on industry was also organized for obtaining information on the various measures to be adopted for rationalization of industrial groundwater use, especially on the feasibility of providing the proposed alternative water sources. Secondary data and information were also collected from relevant government agencies and related literature.

4.1 Perception Survey and Stakeholder Meeting

A perception survey was conducted with the objective of obtaining the views/perceptions of industries on the rationalization of water use and on the possible alternatives for groundwater. The survey was conducted only in Samut Prakan province. Groundwater use is at a maximum in Samut Prakan province, as seen from table 1. Also, considering the various uses, industry uses groundwater the most intensively (71%), as shown in figure 8. Hence industries in Samut Prakan were chosen for the perception survey. The survey was conducted via personal interviews and mailed questionnaires. A sample of 80 industries was selected for personal interview from the industries which use more than 300 m^3/day of groundwater and questionnaires were mailed to 400 industries. The response rate for the interview was 70% (56 respondents), whereas that for the mail survey was only 7% (29 returned). The total number of respondents (both interview and mail) was 85. The survey has shown that 55% of industries depend on groundwater either alone or in combination with piped water supply from MWA. Considering the amount of water used, only 24% of the total water used in the industries comes from groundwater (table 2).

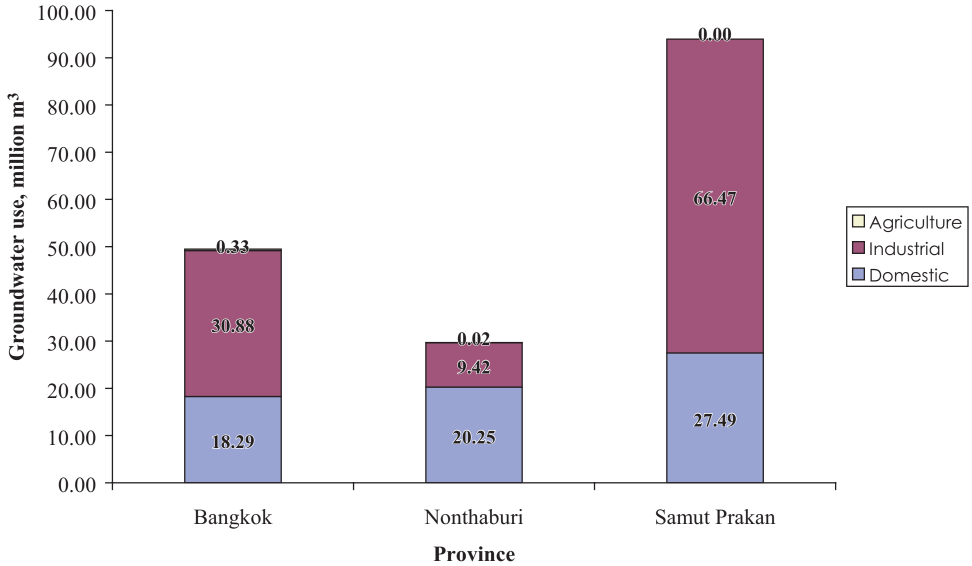

Figure 8. Groundwater Use by Different Sectors in Bangkok, Nonthaburi and Samut Prakan in 2003

Table 2. Dependency of Industries on Different Water Sources and Water Use

Type of industry	Industries using piped water (%)	Industries using only groundwater (%)	Industries using both piped water and groundwater (%)	Piped water in total water use (%)	Groundwater in total water use (%)
Textile	37	7	56	35	13
Food	42	5	53	17	4
Chemical products	43	14	43	2	5
Automobile	67	0	33	9	0
Leather & footwear	0	33	67	0	0
Metal	67	17	17	4	1
Electrical & electronics	33	0	67	7	0
Paper	25	0	75	1	1
Building material	100	0	0	1	0
Plastics	100	0	0	0	0
Total (%)	**45**	**7**	**48**	**76**	**24**

The preference for groundwater by industries is attributed to the following reasons:

No MWA supply earlier: At the time of establishment of some industries, MWA piped water supply was not available in the area, therefore industries had to opt for groundwater pumping. However, there has been a shift from groundwater to piped water use during recent years due to the expansion in coverage of MWA supply and now they retain the groundwater wells as a reserve to use in times of emergency.

Piped water supply quality is not suitable for the industries: The presence of chlorine used for water treatment of piped water for meeting the domestic water quality requirement is not acceptable to some industries, for example in the textile, food and chemical industries.

Industries are not satisfied with the reliability of piped water supply: The industries surveyed have expressed concern over the stability and reliability of the piped water supply. Sometimes the piped water supply is shut down without any prior notice, and this affects production in the industries. Also, a major concern raised by the industries on piped water is that the supply does not satisfy the required pressure at all times.

For determining the effectiveness of the alternatives, a stakeholder meeting was conducted. The stakeholders were also provided examples of success of alternatives such as the introduction of industrial water works and wastewater reuse and recycling in Japanese industries. The discussions also aided in the evaluation of alternatives such as expansion of piped water supply and wastewater reuse and recycling in the Thai context.

The survey results and stakeholder meeting have shown that industries started using groundwater when they did not have access to MWA supply in the area and that the quality and pressure considerations of piped water supply are also factors contributing to their preference for groundwater. This shows that if piped water supply is expanded so that the industries are provided with a reliable and sufficient supply at the required quality and pressure, it can act as an alternative to groundwater. Also, the stakeholders, while evaluating the feasibility of policy recommendations, have identified expansion of piped water supply by MWA and PWA as possible options for addressing the groundwater-related problems.

4.2 Expansion of Piped Water Supply

The MWA is responsible for providing piped water supply in the three provinces considered for the study on alternate water sources. At present, the MWA covers less than 50% of its area of responsibility and provides domestic supply to about 90% of the population. According to the revised master plan for water supply and distribution by the MWA, it is expected to increase the pumped water capacity from 4,063,491 m^3/day in 2002, to 5,727,552 m^3/day (an increase of 40.9%) in 2017. The population coverage is targeted to reach 100% by 2017. For the MWA, the priority is to provide water for domestic consumption. However, the expansion plans should also consider providing the required quantity of piped water to industries. Areas in which there is a greater concentration of industries need to be prioritized in this regard.

The Principal Plan for Industrial Water Management developed by the Department of Industrial Works (DIW) states that the policy banning groundwater use by industries in Bangkok Metropolitan Region has prompted the need for industries to use raw water of 1.4 million m^3/day. A mathematical model study by Kasetsart University (2004) has determined the reduction in groundwater pumpage by the private sector, mainly the domestic and industrial sectors, due to the expansion of MWA services. Accordingly, it is expected that by 2013 there will be a reduction in groundwater use of around 0.32 million m^3/day given the replacement of 5,294 groundwater wells as a result of MWA expansion, as given in table 3. This is, however, based on the MWA expansion plans of 1990.

Table 3. Reduction in Groundwater Pumpage by Expansion of MWA Services

Year	Yearly		Cumulative	
	No. of wells replaced	Reduction in groundwater use (m^3/day)	No. of wells replaced	Reduction in groundwater use (m^3/day)
2004	2,597	130,490	2,597	130,490
2006	1,430	89,590	4,027	220,080
2010	582	40,080	4,609	260,160
2013	685	55,850	5,294	316,010

Source: Kasetsart University, 2004

According to the perception survey, 45% of the industries are using only piped water. The expansion of piped water supply can be an option to increase the surface water use by those industries which are currently depending on groundwater. The main issues associated with piped water which are not admissible to industries include the quality and reliability of supply. If the expansion plans of the MWA consider providing water continuously and at the required pressure, the industries can use a piped water supply with appropriate treatment, if required at the industry level.

The presence of chlorine in piped water is an issue for some industries, such as the textile, food and chemical industries. As the main concern of the MWA is to provide water for drinking purpose, it needs to be disinfected according to the WHO guidelines. It will not be financially feasible to have separate distribution lines for domestic and industrial purposes. But, this can be addressed by storing the piped water for a few (2–3) hours before use in the industrial process. A centralized elevated storage tank can be constructed in the case of industrial estates for this purpose. Water from this centralized elevated storage tank can be provided to the individual industries at the required pressure and quality. For example, of the 52 groundwater wells in the three industrial estates in Bangkok, the Industrial Estate Authority of Thailand (IEAT) has decided to maintain only 25 wells as reserve in case of emergencies, such as shut down of piped water supply by the MWA. Centralized storage tanks will be constructed and industries will be supplied with piped water, but at a slightly higher tariff than that charged by the MWA.

Also, a major share of the water used in industries is for cooling, as boiler feed and for cleaning, and these processes do not require a high quality of water. Hence, the industries that are heavy users of groundwater can shift to using piped water in those processes in which quality is not of much concern.

Presently, the percentage of coverage by the MWA with respect to area is only around 50%. The investment cost is high for laying out pipelines if the industries are far from the main pipeline. But in the third stakeholders' meeting, the MWA expressed its willingness to support the industries with respect to the cost of the pipeline system and the MWA would consider such requests on a case-by-case basis.

A significant impediment in using piped water as an alternative water source by industries using groundwater is the resistance to change. The groundwater users are reluctant to use piped water, as they are not sure of the problems they would face if they shift to piped water and hence they are not ready to take risks.

The MWA is also trying to promote the use of piped water by industrial sector. As part of the promotion plan, piped water is initially supplied at a lower rate of 13 THB/m^3 to the industries. When the industries become convinced with the supply reliability and quality, they start using more piped water and after three years the normal tariff is charged. Such promotion measures, if coupled with other incentives from the Government, can help increase the use of piped water by the industries that are heavily dependent on groundwater.

4.3 Wastewater Reuse and Recycling

Wastewater reuse and recycling, if adopted in industries, can help better efficiency of water use and results in water and cost savings. Recycled and reuse water are considered alternative resources and should be taken into account for water resources planning and management. This has been very successfully implemented in various industrialized countries like Australia, Germany, Italy, Japan, Singapore, the United States, etc. (Urkiaga, A., 2004). As an example, in Japan, in spite of rapid industrial development, the industrial sector has reduced its dependency on groundwater and shifted to using more recycled water. The percentage of recycled/reuse water use has increased from 21% in 1960 to about 80% in 2000. These success stories can be adopted in Thai industries as well, with suitable modifications to suit Thai conditions.

Reuse and recycling are adopted as strategies to improve water use efficiency in industries in the National Water Strategies developed by the Water Resources Association of Thailand. However, presently wastewater reuse and recycling are adopted as waste minimization techniques rather than as water-saving measures. The National Integrated Waste Management Plan has adopted the 3Rs (Reduce, Recycle and Reuse) as the major strategy. The National Master Plan on Cleaner Production (CP) developed by the former Ministry of Science, Technology and Environment has the vision of controlling pollution and management of natural resources and environment. The DIW, in its 'Principal Plan for Industrial Water Management,' states the need for adopting these practices in industries. It also underlines the necessity of reducing groundwater use by industries.

Transfer of technology as a measure for capacity strengthening in the DIW, with respect to the effective use of water in industries, is provided by the Japan International Cooperation Agency (JICA), which also resulted in the setting up of an Industrial Water Technology Institute (IWTI) (JICA and DIW, 2000). A Cooperative Research Project on the Development of Environmentally Friendly Industrial Wastewater Reuse Technology is being undertaken by DIW in collaboration with the New Energy and Industrial Technology Development Organization (NEDO), Japan. The target group of industries for the project includes the textile and food industries.

From the perception survey, it was observed that there is a fairly good adoption, with 59% of the surveyed industries adopting wastewater reuse and recycling practices. The survey has also shown that 31% of the industries reuse/recycle wastewater in the cleaning process, 16% used for cleaning, 23% in boilers, 19% in cleaning machinery and 23% in uses other than in production processes, such as watering plants, cleaning floors and flushing toilets. Many of the industries, which are in the process of applying for ISO 14000 certification, are planning to incorporate wastewater reuse as their future management goal.

The industries, being profit-oriented, will adopt wastewater reuse and recycling only if they prove to be cost-effective and competitive. The MWA piped water is supplied at a charge of 16 THB/m^3. Hence, if they are to adopt wastewater reuse and recycling, it should be comparatively cheaper in terms of investment and recurring costs.

Pilot studies on Cleaner Production (CP) technologies conducted in Carpets International Thailand PCL (CIT), also determined the efficiency of input use and technical and economic feasibility of reuse and recovery. It was found that the cost for modification of the existing systems and for upgrading the wastewater treatment plant to accommodate separate treatment of wastewater amounted to 12 million THB and the expected water saving by recycling was equivalent to a saving of 7 million THB/year in water bills. This brings the payback on investment for reuse and recycling to less than 1.7 years. Thus, the adoption of these practices was found to be economically feasible (Franknel, R.J., 2005).

Even though wastewater reuse and recycling can be economically feasible, there are some institutional and management issues associated with the large-scale adoption of the practices in the Thai industries, as mentioned below:

Institutional and Management issues: No legislative arrangements are in place to promote wastewater reuse and recycling. Also, there are no proper guidelines for the implementation of the practices. Industrial wastewater reuse/recycling are being practiced as measures to control pollution, which is the responsibility of many agencies. There is a lack of proper coordination between these agencies and industries. The industries are not fully aware of the advantages of water saving by the adoption of these practices. The lack of incentives and subsidies from the Government side are also bottlenecks in the widespread adoption (Viswanathan and Cippe, 2001).

Potential policy approaches that can be followed for widespread adoption of wastewater reuse and recycling in Thailand are as follows:

i. Legislation and regulations for wastewater reuse and recycling should be in place, and it should focus more on potential water savings in industries.
ii. Financial incentives from the Government side are needed for successful implementation. The reuse and recycling processes, if adopted, need additional treatment facilities, which require high investment cost. The

financial incentives can be either as support in the initial investment or as a tax refund/discount for those industries adopting the practices.

iii. The development of industrial wastewater reuse permit structure and guidelines.

iv. The industries in which reuse and recycling has to be adopted should be prioritized based on factors such as their water consumption or pollution load. Water productivity benchmarks need to be established to increase industrial production using less water.

v. The regulations on pollution control also need to be effectively implemented, such as the collection of wastewater discharge fees. Fines need to be collected for non-compliance of regulations.

vi. Better co-ordination needs to be achieved between the different agencies such as the DIW, IEAT, FTI and individual industries for successful implementation. An alternative that can be adopted is that the group of industries in the industrial estates can join together to have a wastewater treatment plant and the treated water can be supplied to the individual industries.

vii. Research and development on the technology that is suited to the Thai context should be promoted.

viii. Creating awareness among the industries, especially Small and Medium Enterprises (SMEs), on the cost savings and water savings that can be achieved by adopting wastewater reuse and recycling.

5. Conclusions

Extensive use of groundwater in the Bangkok Metropolitan Region started in the mid-1950s primarily for public water supply. But, at present, private usage of groundwater has become more significant, mostly by the industrial sector. Of the eight layers comprising the aquifer system, the most utilized are the second (Phra Pradaeng), third (Nakhon Luang), and fourth (Nonthaburi) layers from the ground surface. Over-exploitation of groundwater has resulted in various environmental problems, such as extreme lowering of water tables, land subsidence, and increased salinity of aquifer yields in the Study Area. These problems led to the formulation of various mitigation measures by the Government of Thailand, such as promulgation of the Groundwater Act, defining critical zones, licensing and metering of groundwater wells, introducing groundwater use and preservation charges, etc.

Nevertheless, groundwater-related problems still exist in the Bangkok Region. Hence, improvements are needed in the existing policies and new policies need to be formulated. Through this research on SWMP (Sustainable Water Management Policy) integrated policy options for sustainable groundwater resources management in the Study Area are proposed. The proposed policies include direct control, economic, supporting, technical and informative measures. As the industrial sector is the major user, alternative water sources for rationalizing the groundwater use in the industries, such as expansion of piped water supply and wastewater reuse and recycling, are also proposed. For the industries to shift from groundwater to piped water supply, good quality of water with a reliable supply has to be ensured.

To be able to translate policy proposals to concrete actions, it is recognized that proper enabling environments for implementation must be established. Proposed new or improved measures developed on the basis of sound knowledge are good starting points. But, most importantly, proper implementation of improved policies for groundwater management in the Study Area requires the dedication and commitment of responsible government agencies, as promulgation of recommendations into actual national laws and policies and activities requires much time and effort from the concerned authorities.

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