



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

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).

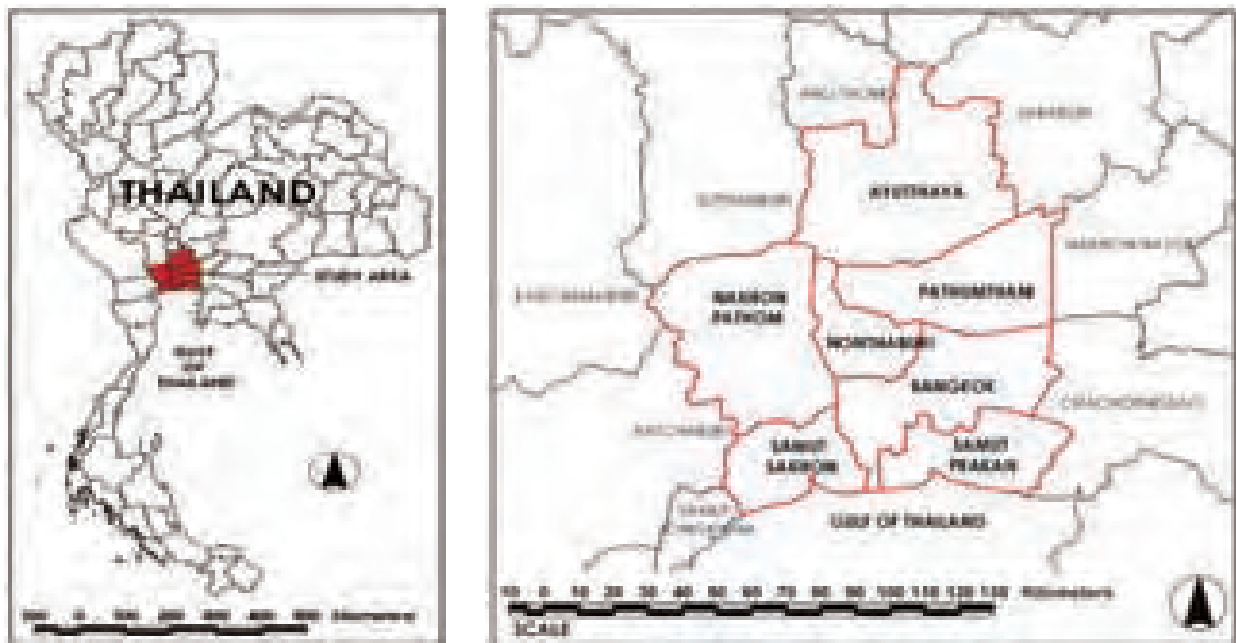


Figure 1. Thailand Case Study Area

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 km², the average population density in the Study Area was about 1,000 persons/km² 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 km² in area (Kasetsart University, 1998). In 1996, total water demand in the Lower Chao Phraya Basin was estimated at 17,500 million m³/year consisting of 16,900 million m³/year surface water and 600 million m³/year groundwater. By 2016, it is estimated that this amount will increase to more than 18,000 million m³/year, comprised of 17,400 million m³/year of surface water demand and 800 million m³/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 m³, which was more than 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 m³ 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 m³/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 m³) 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 m³) 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 m³/year in 1996, and that this will increase by about 22% to 1,335 million m³/year by 2006 and by 34% to 1,469 million m³/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 km², and in 2003, MWA water supply service covered 1,515 km² 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 agrowells 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 m³/day from 8,360 m³/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 m³/day. It reached its peak in the late 1970s and early 1980s, amounting to 464,000 m³/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).

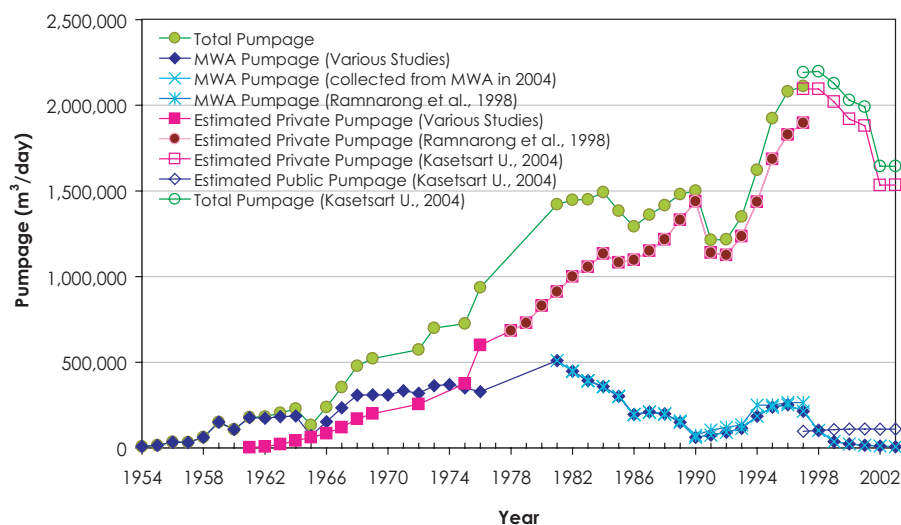


Figure 2. Groundwater Pumpage in Bangkok and Surrounding Areas

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 m³/day since 1997, varying from 2.2 million m³/day in 1997 to 2 million m³/day in 2001, and decreasing to 1.7 million m³/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 m³/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 m³/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).

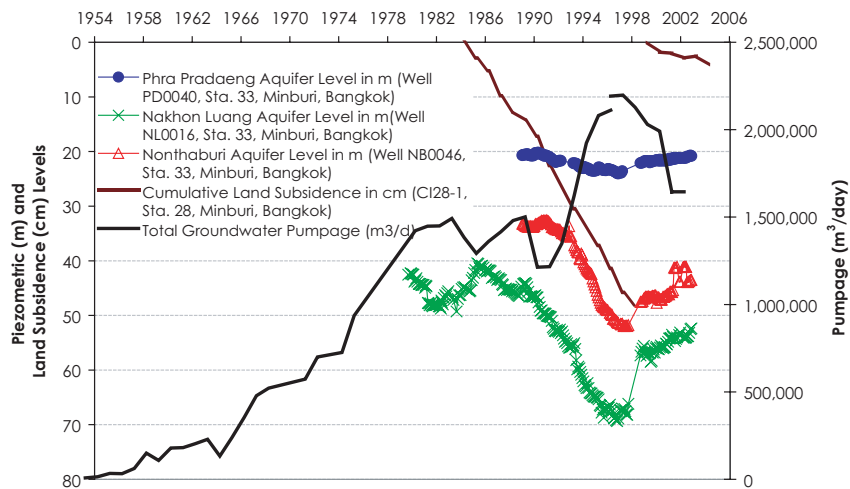


Figure 3. Total Groundwater Pumpage in Bangkok and Surrounding Areas, and Piezometric and Land Subsidence Level Variations in Minburi, Bangkok

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).

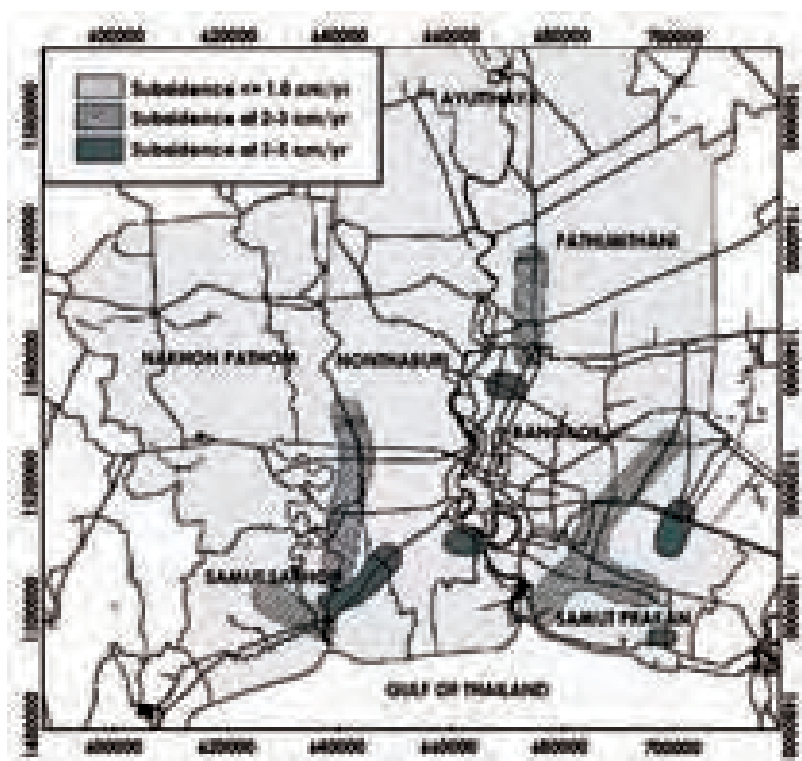


Figure 5. Map Showing Land Subsidence in 2003
 Source: DGR 2005

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.

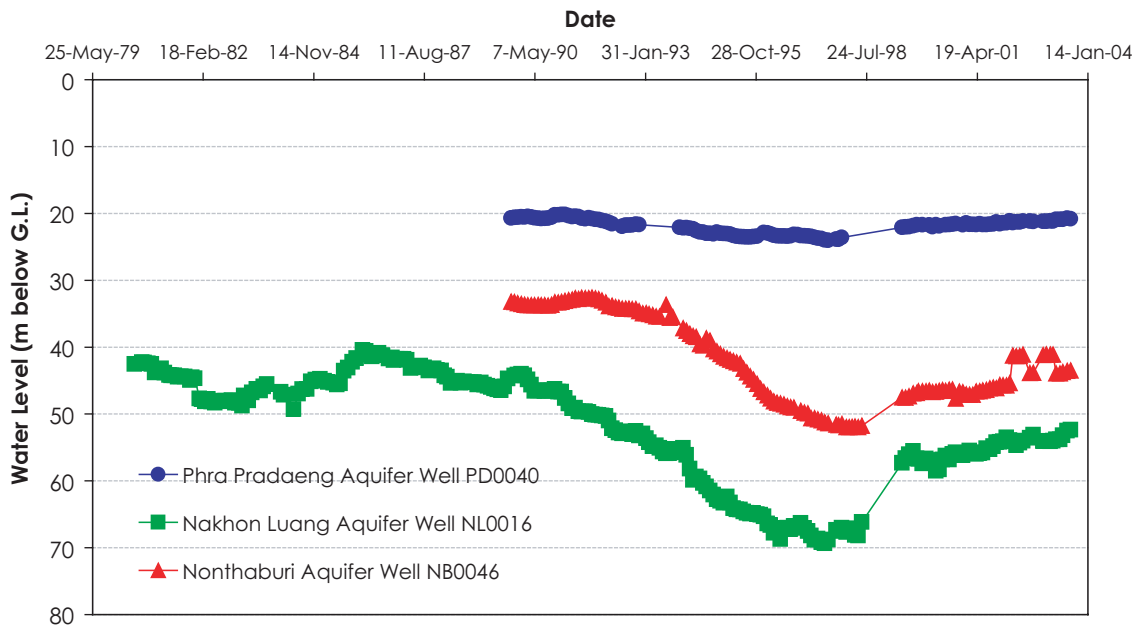


Figure 6. Groundwater Level Variation in Station 33: Minburi, Bangkok

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/m³, 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/m³ (July 2000) to 8.50 THB/m³ (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/m³ (1 September 2004), the charge is set to increase to 8.50 THB/m³ 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/m³ in 2004, to 12.50 THB/m³ by mid-2005, and to 17 THB/m³ 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/m³ 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 m³/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.

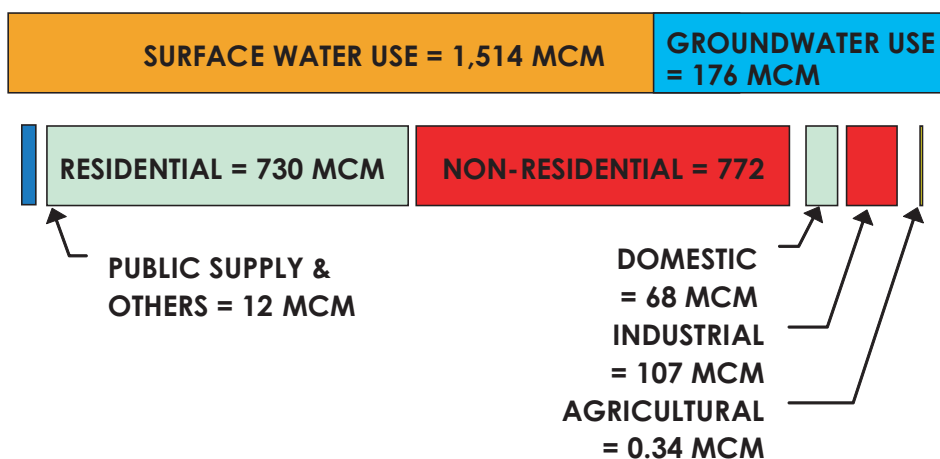


Figure 7. Current Water Use by Various Sectors in Bangkok, Nonthaburi and Samut Prakan, for the Year 2003
Note: MCM means million/m³

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 m³/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).

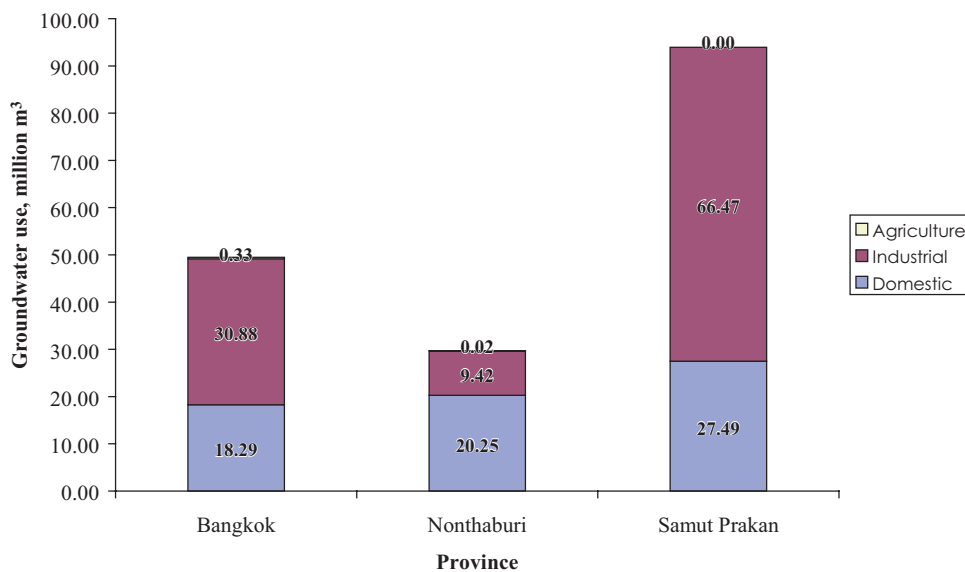


Figure 8. Groundwater Use by Different Sectors in Bangkok, Nonthaburi and Samut Prakan in 2003

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 m³/day in 2002, to 5,727,552 m³/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 m³/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 m³/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/m³ 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/m³. 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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