WATER DEMAND MANAGEMENT MODEL IN THE LOWER CHAO PHRAYA RIVER BASIN, THAILAND

Pongsak SUTTINON

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Department of Engineering
Graduate School of Engineering
Kochi University of Technology
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Abstract

Providing water for rapidly increasing of population, urbanization, and developing economics activities in agricultural, industrial, and service sector is increasingly difficult for many cities around the world. Lower Chao Phraya River Basin including Bangkok (the capital of Thailand), and Vicinities is one of the area faced with high development of economic activities such as industrial and service sector with constraint of water supply.

Not only economic activities were changed, but water demand was changed also because an increase in demand of output resulted from declared policies is likely to cause a rise in need of all infrastructures especially water. From this reason, the higher demand in the future which is needed to produce the target growth of gross domestic product or GDP is motivated force for all level of related governmental agencies.

There are two main water management system; water supply and demand schemes. The predominant approach for the past is generally water supply schemes; however, developing new water sources is more difficult because of limited water supply, conflict with environmental viewpoint, and higher cost of water per cubic meter. It is almost certain that water demand management is increasing powerful with ideas of improving efficiency and sustainable use of water with considering economic, social and environment.

In this research, water demand management model with source code was developed in details of each water user in industrial, household, and agricultural sector. The objective of this research is to develop toolbox of integrated water demand management for supporting professionals and policy makers in Thailand especially the Lower Chao Phraya River Basin who take responsibility on management of water resources. This research provides guidance for assessing and forecasting not only water demand, but also the impacts from declared strategy by using socio-economic measures.

The water demand management model is divided by using 4 main models; Input-output table, industrial, domestic, and agricultural model including irrigation and livestock model.

Firstly, Input-output table model was developed to analyze changing economic structure by using economic scenarios of national and international scale. Next, water use unit in

each sector was calculated by using secondary data from Thai government agencies and questionnaires for industrial and domestic sector. After previous step, water demand in each sector was forecasted under economic scenarios. Water supply was analyzed under constraints of each water source affected from future master plan, laws, regulations, and climate.

For non-agricultural sector, governmental option scenarios with equilibrium analysis, water demand-supply curve, and pricing policy were applied to calculate the impacts to Thai economic structure or target. Policy makers can use the result from this step to make decision with declared strategy policy under limitation of water in form of GDP or monetary term. Next, strategic decision making was applied for non-agricultural sector for considering whether and how to invest the water infrastructure under uncertainty of water demand growth rate in the future. Finally, integrated water demand model was developed to manage water and benefit sharing analysis.

The results show that the economic activities especially industrial sector resulted from declared domestic and international strategies from government agency will be rapidly developed in the future. However, there are conflicts of water quantity to support the target growth of Gross Domestic Product (GDP) because of groundwater ban from the law and high density of much groundwater consumers such as food and textile factory concentrated by industrial master plan. For household sector, main effect for rapidly growing of water demand is water use unit from higher daily style with urbanization. The growth rate of population is gradually decreasing because of becoming small family in big city.

For non-agricultural sector, the policy makers have many measures to manage water demand-supply by using demand-supply curve with pricing policy and governmental option scenarios such as with/without infrastructure structure and with/without subsidy from public sector. The suitable countermeasure is depending on evaluation standard in each situation. Finally strategic decision making model was applied to calculate whether new water infrastructure should be invested under uncertainty of water demand growth rate in the future and how to invest it.

Agricultural sector generally consumed water in high percentage of total use especially rice in the upper part of study area. Only rice and sugarcane is mainly planted in study area because of physical soil condition of clay in the lower part. It is almost certain that planted area in study area is gradually decreasing because urbanization. However, second rice crop planted in irrigation service area is developing to the full capacity of possible agricultural area.

In the year 2025 or next twenty years, industrial and household sectors will play a role of main water consumers in this area with 61 % of water share from 45 % in year 2006. The rapid growths are resulted from industrial sector because of declared domestic and international governmental plan with changing water share from 20 % in 2006 to 34% in 2025. Household water will be increasing needed because of higher water use unit. The growth rate of agricultural sector is much less than industrial and household sector because of decreasing crop area.

Policy maker should concern how to control higher industrial water demand with limited water supply. One of interesting option is recycled water that don't need new water source. However, higher unit cost of water is the main topic concerned by water user and provider. The choice is whether governmental agency subsidizes this higher cost with keeping the target growth of GDP.

Finally, water right and benefit sharing analysis is the topic in the practical implement. Suitable water right and benefit sharing cannot be happened without the negotiations among each user. Firstly, each user should make the decision by themselves and government agencies and specialist should be only consulting person with constraints and possible conditions.

Acknowledgement

Sincere appreciation is extended to several professors and specialists who commented on my research especially my advisor, Prof. Seigo Nasu who gave me a good chance to study and do an interesting research with his valuable advice and warm support. I would like to thank for my research examination committees; Professor, Dr. Osamu Tomisawa, Professor, Dr. Masataka Takagi, Assoc. Professor, Dr. Masahiro Ouchi, and Assoc. Professor, Dr. Sucharit Koontanakulvong. Their efforts resulted in many improvements.

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I would like to thank Chulalongkorn University and Thai government agencies for the useful data, kind discussion and comments. Many thanks are extended to all my friends in Nasu laboratory including Ms. Michiko Mizobuchi and Ms. Rieko Tobisaki, Prof. Nasu's secretaries for their experiences, discussions, helps and enjoyments. I also would like to extend my thanks to all my Japanese and foreign friends.

Finally, I would really like to say "Thank you very much" for my dad, mom, and my family in Thailand who always support me to the right way. Thank you for my wife and baby that will be born in 2008. They are my motivation to do the best.

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Chapter 1

Introduction

1.1 Background

Providing water for rapidly increasing of population, urbanization, and developing economics activities in agricultural, industrial, and service sector is increasingly difficult for many cities around the world. The predominant approach for the past is generally water supply schemes; however, developing new water sources is more difficult because of limited water supply, conflict with environmental viewpoint, higher cost of water per cubic meter.

From the difficulty of water supply scheme in recent year, saving water was been considering more than developing new water sources. Water demand management is an appropriate toolbox for improving efficiency and sustainable use of water with considering economic, social and environment as shown in figure 1.1.

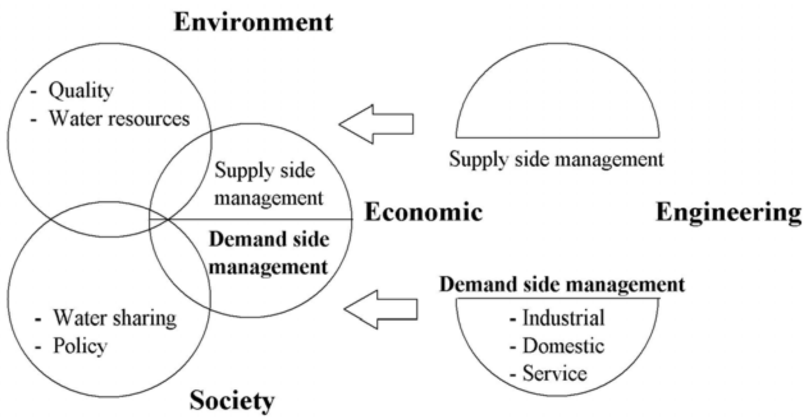


Figure 1.1.Conclusion from discussion with Thai government agencies.

One interesting example of water use and supply management is case of Tokyo in Japan shown in figure 1.2. In the period of 1965-1972, water demand was rapidly increasing because of rapid economic growth, increasing population and industrial concentration in Tokyo. In that period, Tokyo planed to construct new water infrastructure such as dam, and pipeline system to support higher water demand. In the second period after oil crisis in 1973, water demand decreased sharply because of low economic growth, water demand control measures, and movement of production base. After construction of new dams in 1985 and 1993, Tokyo has a big water supply with rapidly decreasing water demand. The gap between water supply capacity and water demand means losses of budget for construction, operation and maintenance cost for unused water.

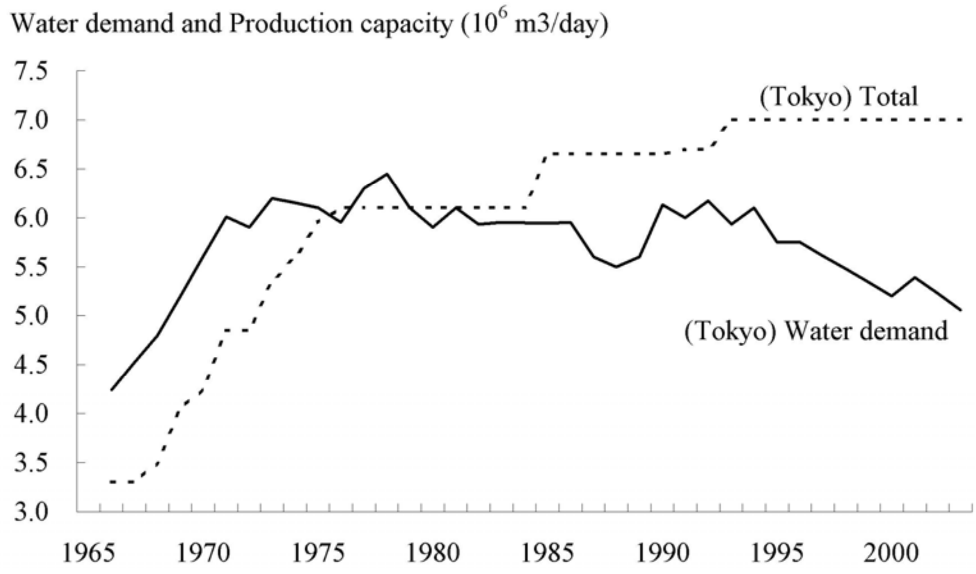


Figure 1.2 Water demand and supply capacity in Tokyo

（Source: http://www.metro.tokyo.jp）

In case of the study area as Lower Chao Phraya River Basin, there are similarities with case of Tokyo as follow; (1) both areas are the capital and central of economic activities of national scale, (2) rapid economic growth before economic crisis or oil crisis, and (3) groundwater ban law to protect critical land subsidence. Now it is very difficult to develop new water resources by constructing dams or water supply measure. It is imperative that study area aims to become a water conservation conscious country by making the most effective use of water resources or water demand management.

1.2 Basic definitions

Water demand is the quantities of water that users consume per unit per time such as drinking water for household sector, water for production process in industrial sector, and water for rice in agricultural. Water use is divided into 2 groups; (1) water is used but not withdrawn from water source such as; fishing, hydropower-generation, navigation, environmental protection, (2) water is used and withdrawn from water source as same case as water demand.

In this research, water demand management is mainly analyzed with economic measures by using mainly Input-Output (I-O) table. From that reason, water demand will be defined with the economic activities in I-O table as follow;

- Industrial water demand is water use in all industrial activity (code 030-134 in I-O table) including water use in process of production (raw material and washing), utility (cooling and boiler), and office.
- Household water demand includes residential (houses and apartment) and all activity in service sector (code 135-180 in I-O table) such as; commercial (hotel and business), institutional (school and hospital), and other water uses.
- Agricultural water demand is divided into 2 group; (1) water for irrigation and (2) water for livestock (code 001-029 in I-O table).

1.3 Objective

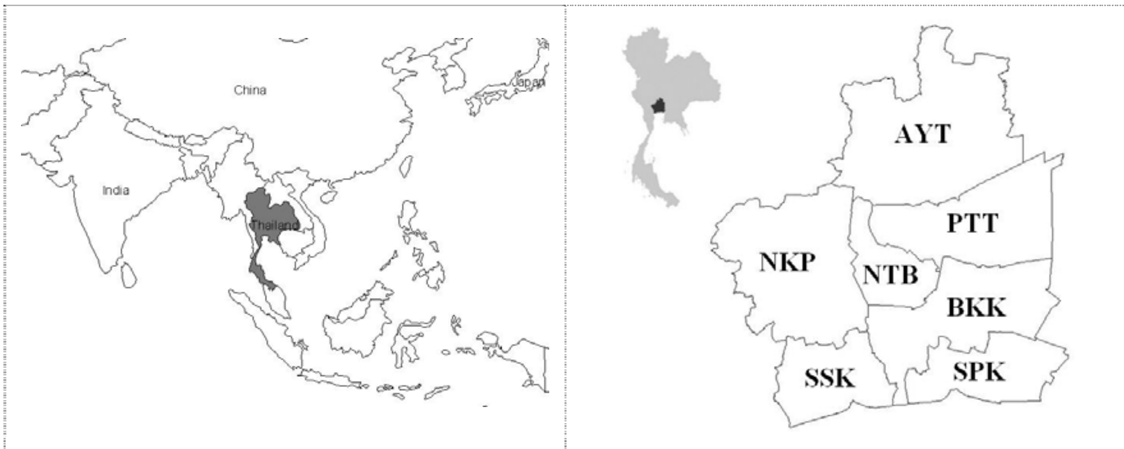
The objective of this research is to develop toolbox of integrated water demand management for supporting professionals and policy makers in Thailand especially the Lower Chao Phraya River Basin who take responsibility on management of water resources. This research provides guidance for assessing and forecasting not only water demand, but also the impacts from declared strategy by using socio-economic measures. The details of objectives in each sector are shown in part II.

1.4 Study Area

1.4.1 Location

Thailand is located in Southeast Asia. Thailand borders the Lao People's Democratic Republic and the Union of Myanmar to the North, the Kingdom of Cambodia and the Gulf of Thailand to the East, the Union of Myanmar and the Indian Ocean to the West, and Malaysia to the south. From the mountain ranges in the northern and western zone, the Ping and Nan rivers flow down to the central part, deltas, and the Gulf of Thailand by order. This central part is named Chao Phraya River Basin.

Study area shown in figure 1.3 is located in the Lower Chao Phraya River Basin (LPCRB) with 7 provinces as follow; Bangkok (BKK), Samut Prakarn (SPK), Nonthaburi (NTB), Pathum Thani (PTT), Ayutthaya (AYT), Nakhon Pathom (NKP), and Samut Sakhon (SSK).



(a.) Thailand scale (b.) Study area scale

Figure 1.3. Map of Thailand and study area.

1.4.2 Thailand in the world

Population and national area

Population in Thailand shown in figure 1.4 is 63 million persons in 2006 or approximately 0.5 time of Japan. National area of Thailand is 513 thousand km^2 or 1.4 times of area of Japan. It means that population density of Japan, 322 persons per km^2, is more than 2.8 times of case of Thailand. Population density in Thailand is as similar as EU at 122 persons per km^2, but the rate in U.S.A is small with 31 persons per km^2 because of large national area.

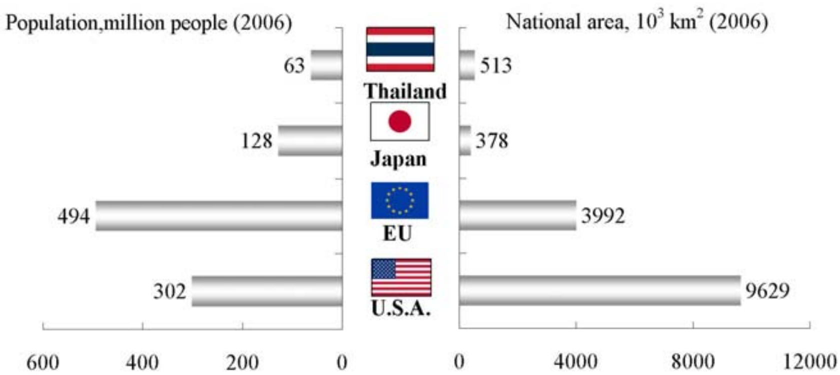


Figure 1.4. Population and area of Thailand, Japan, EU, and U.S.A.

(Source: http://www.un.org)

Economy

Gross Domestic Product or GDP is sum of gross value added that is the net output of an industry after adding up all outputs and subtracting intermediate inputs. GDP is generally shown in Input-output table which includes the economic activities in the country, input and output, and interrelationship of each activity.

GDP of Thailand shown in figure 1.5 is $206*10^9$ \$ in 2006 or 33rd position of the world. The first rank of GDP is United States with $13{,}202*10^9$ \$ or 64 times of GDP of Thailand. If GDP is separately considered in each country, Japan is the second rank in the world approximately $4{,}340*10^9$ \$ or 33 percent of GDP of U.S.A. however, if European Monetary Union is considered as one group, GDP of EU is the second position with $10{,}526*10^9$ \$ or 78 percent of GDP of U.S.A. GDP per capita of Thailand is 3,289 $ in 2006 or approximately 10 % of Japan.

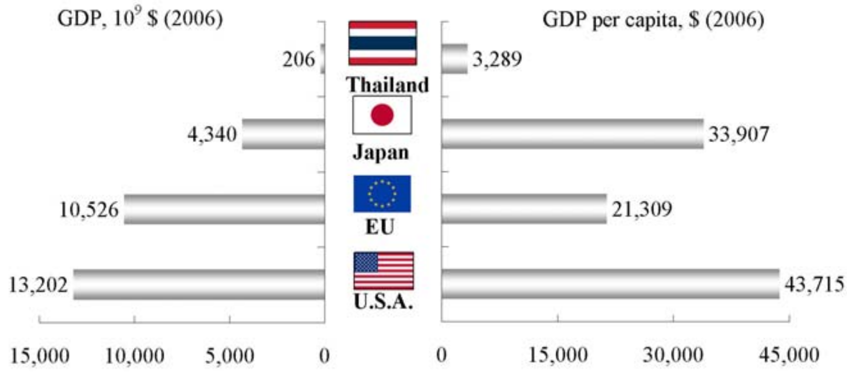


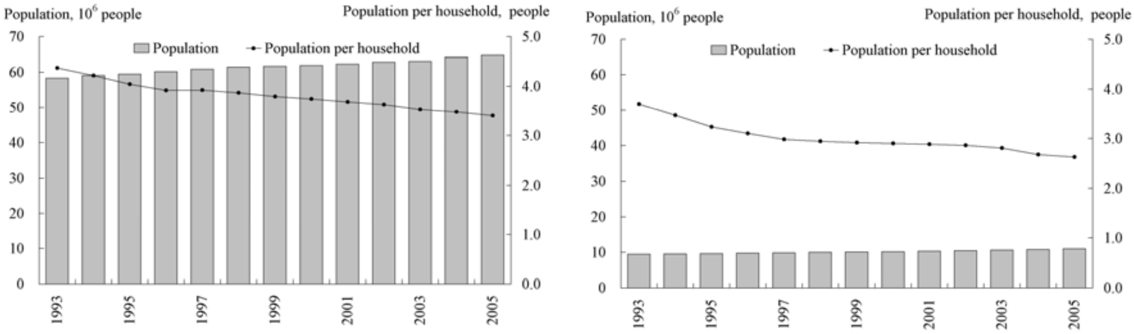
Figure 1.5. GDP and GDP per capita of Thailand, Japan, EU, and U.S.A.

(Source: http://www.worldbank.org/)

1.4.3 Study area

Population

Figure 1.6 shows number of population and population per household in national and study area scale. Bangkok (capital of Thailand) and vicinities are located in this study area. From this reason, there are 10.9 million registered persons lived in study area mainly in Bangkok. This high population is approximately 17 % of Thailand. The trend of population per household was gradually decreasing in both Thailand and study area scale. The reason is new generation need less children with success birth control strategy form governmental side. However, population per household in study area is less than national scale because the family size in big city as Bangkok and vicinities is generally smaller than rural area.



(a.) Thailand scale (b.) Study area scale

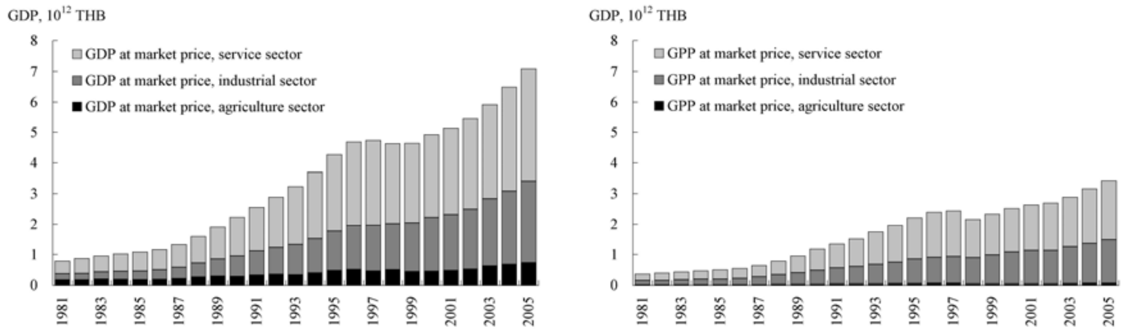
Figure 1.6. Number of population and population per household in national scale and study area.

(Source: http://www.dopa.go.th)

Economy

Figure 1.7 shows economics situation as gross domestic product at market price or GDP since 1981 in national and study area scale. The main economics activity is service and industrial sector in both Thailand and study area. The trend of growth rate of GDP in service and industrial sector were rapidly growing compared with agricultural part; however, in year 1998, GDP of industrial and service were suddenly dropped because of economic crisis. The GDP growth rate of agricultural is constant and not sensitive with total trend of GDP even in the period of economic crisis in 1998. From the previous topic, population in study area is only 17 % but can produce GDP approximately 48 %. It means that this area is not only central part of political and government but main sector of economics activities in industrial and service sector also.

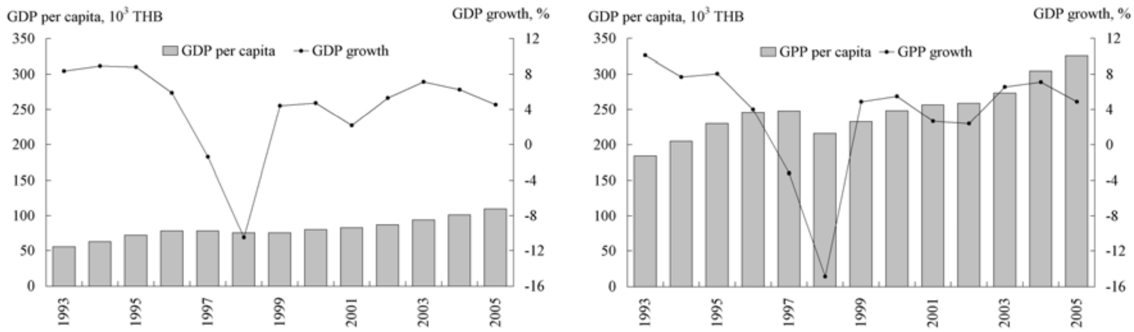
Figure 1.8 shows GDP per capita, gross regional product per capita, and GDP growth in Thailand and study area scale. GDP per capita in study area is approximately 3 times of Thailand because this area is central of economic activities. In case of GPP growth, the fluctuation of growth rate in study area is more than national area, however, it means that the damage from economics crisis in year 1998 is higher also approximately -15%. Despite the recent growth, GDP per capita remained flat over the period since 1995 in national scale.



(a.) Thailand scale (b.) Study area scale

Figure 1.7. Gross domestic product of Thailand and study area at market price.

(Source: NESDB)



(a.) Thailand scale (b.) Study area scale

Figure 1.8. Gross domestic product of Thailand and study area at market price.

(Source: NESDB)

Climate, Rainfall, and Runoff

Table 1.1 shows climate data in study area collected by Thai Meteorological Department. This data is important input data to calculate water use unit in each crop.

Table 1.1 Climate data in Chao Phraya River Basin.

Climate data	Unit	Range	Average
Temperature	Celsius	27.9 - 28.4	28.1
Humidity	%	70.4 - 74.9	72.8
Wind velocity	Knot	2.1 - 8.8	4.1
Cloud index	0-10	5.4 - 7.6	6.3
Pan evapotranspiration	mm.	1,782.5 - 2,018.0	1,873.6
Crop evapotranspiration	mm.	1,722.6 - 2,045.5	1,916.3

Source: The Project of 9th Water Resources Master Plan and Irrigation Projects (RID2003)

Table 1.2 shows rainfall depth in Chao Phraya River Basin (CP.). The season is divided into 2 seasons; rainy season (May-Oct) and dry season (Nov-Apr). 90 % of rainfall is in rainy season.

Table 1.2 Rainfall depth in Chao Phraya River Basin (mm.).

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Rain	Dry	Total
CP.	50	132	119	132	160	252	162	30	6	6	12	23	957	126	1,083
Thai	72	179	179	191	230	247	155	75	34	15	15	33	1,180	244	1,424

Source: The Project of 9th Water Resources Master Plan and Irrigation Projects (RID2003)

Note: C.P. is Chao Phraya River Basin, Thai is Thailand

Table 1.3 shows runoff in Chao Phraya River Basin. The characteristic of runoff in CP. is as same as rainfall. Runoff in rainy season is 97 % of total runoff.

Table 1.3 Runoff in Chao Phraya River Basin (10^6 cu.m.).

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Rain	Dry	Total
CP.	2	42	21	22	91	872	608	38	18	13	4	1	1,657	75	1,732

Source: The Project of 9th Water Resources Master Plan and Irrigation Projects (RID2003)

Note: C.P. is Chao Phraya River Basin

1.5 Methodology

Figure 1.9 shows schematic diagram for water demand management model in the Lower Chao Phraya River Basin, Thailand. The model is divided into 4 main models; Input-output table, industrial, domestic, and agricultural model including irrigation and livestock model. The detail of each model was shown in part II (chapter 3-6).

Firstly, Input-output table model was developed to analyze changing economic structure by using economic scenarios of national and international scale. Next, water use unit in each sector was calculated by using secondary data from Thai government agencies and questionnaires for industrial and domestic sector. After previous step, water demand in each sector was forecasted under economic scenarios. Water supply was analyzed under constraints of each water source affected from future master plan, laws, regulations, and climate.

For non-agricultural sector, governmental option scenarios with equilibrium analysis, water demand-supply curve, and pricing policy were applied to calculate the impacts to Thai economic structure or target. Policy makers can use the result from this step to make decision with declared strategy policy under limitation of water in form of GDP or monetary term. Next, strategic decision making was applied for non-agricultural sector for considering whether and how to invest the water infrastructure under uncertainty of water demand growth rate in the future. Finally, integrated water demand model was developed to manage water and benefit sharing analysis.

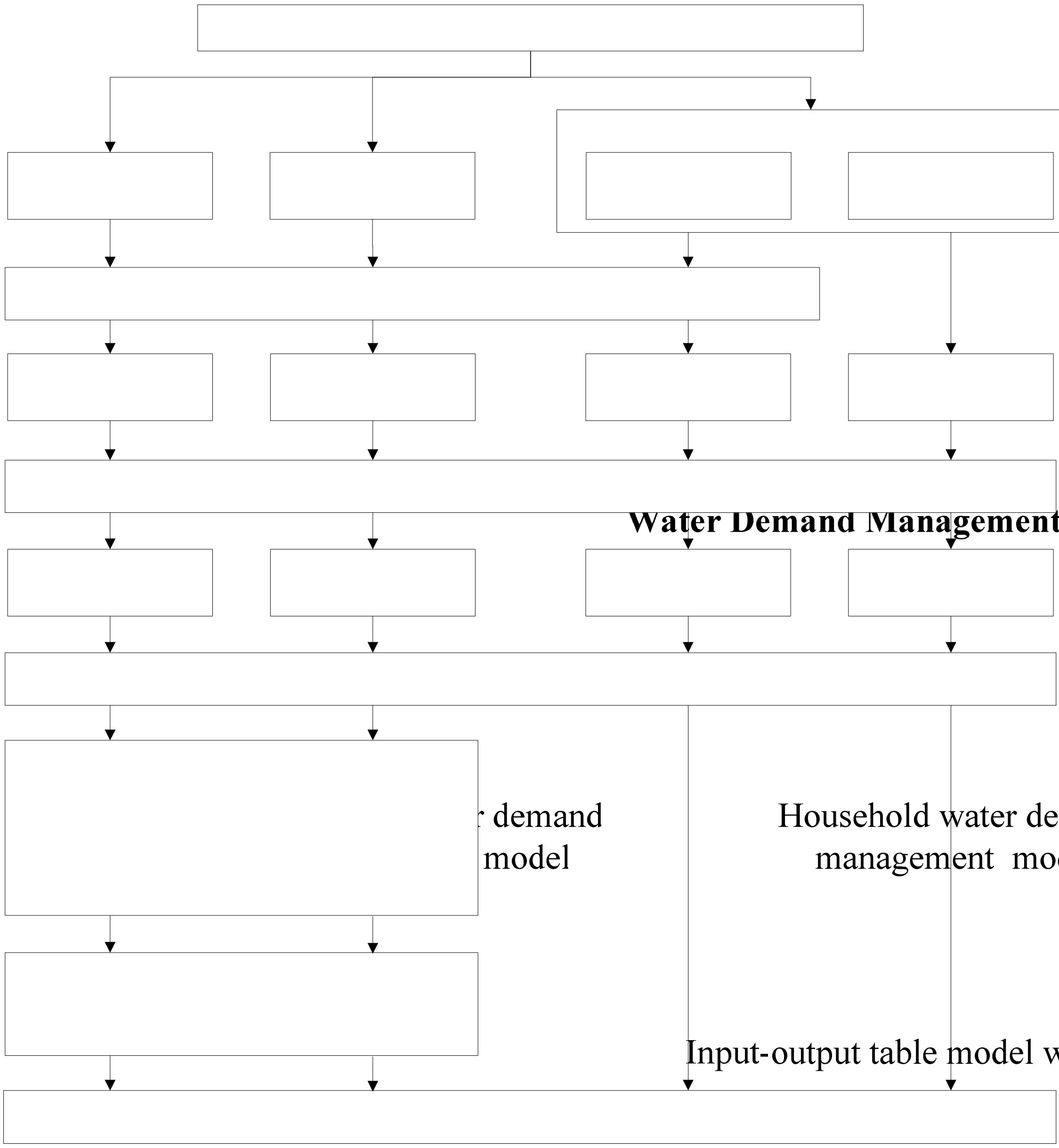


Figure 1.9. Schematic diagram.

This developed toolbox is one interesting tool for Policy makers to make decisions with these questions;

1. How much water do they need to support declared national and international plan?

2. How much water do they have under constraints of each water source, laws, and regulations?
3. What is the suitable alternative under more demand with limited supply to keep the target of development? If there is shortage problems, how to solve it? There are many measures to control water situation with keeping economic target, for example, pricing policy, governmental option policy (with/without new water infrastructure and with/without subsidy higher cost of water in the future), recycled water, water leakage reduction system. Which measure is suitable?
4. What is the impact to economic structure from changing water structure by declared policy and measure depending on different evaluation standard?
5. Is it suitable to invest water infrastructure under uncertainty of water demand growth rate affected from unstable situation of economic? If it should be invested, how to invest?
6. How does water share among each sector in the critical period such as dry season under the maximum satisfaction of each user because of each water user need more water and want to keep the spared water as much as possible?

1.6 Organization of Dissertation

This structure of this dissertation is shown as follow:

Part I: Research introduction and reviews

- Chapter 1 outlines background, objective and scope of research with details of study area and methodology for water demand management model;
- Chapter 2 shows literature reviews of water demand model in industrial, household, agricultural sector and water demand management

Part II: Development and application of economic-water demand supply model

- Chapter 3 details Thailand and provincial Input-Output model to calculate changing economic activities from declared governmental strategy and international agreement;
- Chapter 4 shows industrial water demand model as follow; 1) water demand modeling including IO table with economic scenarios and water unit analysis, 2) water supply analysis with future plan, 3) integrated industrial water demand modeling with equilibrium analysis, price elasticity, governmental option scenarios, recycled rate scenarios and 4) risk management with water infrastructure investment for industrial sector;
- Chapter 5 details household water demand model as follow; 1) population model

including impacts from changing economic activities and water unit analysis, 2) water supply analysis with future plan, 3) integrated household water demand modeling with equilibrium analysis, price elasticity, governmental option scenarios, and 4) risk management with water infrastructure investment for household sector;

- Chapter 6 shows agricultural water demand model including irrigation and livestock sector.;

Part III: Conclusions and Recommendation

- Chapter 7 describes conclusions and recommendation from this research.

Chapter 2

Literature reviews

2.1 Water use and economic

In this section, water use and economics situations were described in case of many countries around the world as follow; United States, Hong Kong, China, and Japan. Gleick et al. (2003) present interesting relationship between water uses with economics condition.

Figure 2.1 and 2.2 show gross national product of United States, water withdrawals, and economic productivity of water. From 1900s to 1970s, the trend of water withdrawals is as same as the trend of GNP as shown in figure 2.1. In this period, the economic productivity is relatively constant at 6.8 $ of gross national products per cubic meter of water as shown in figure 2.2. However, after 1970s, the water withdrawals were decreased and relatively constant although GNP was still growing. In the period, the economic productivity of water rose steadily because of combination of factors as follow; rising environmental awareness, advances in technology, and the shift towards a service economy.

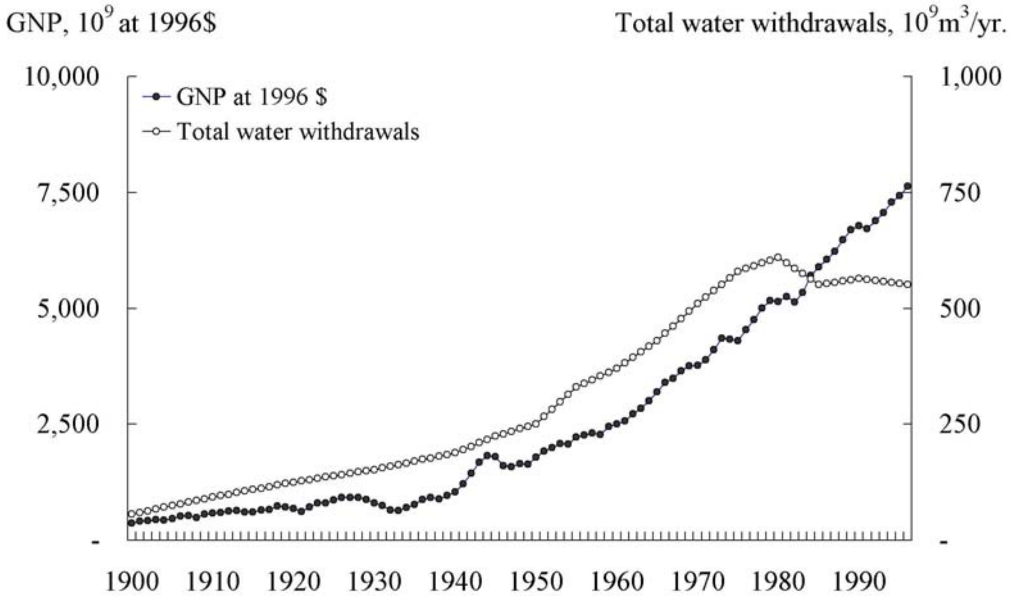


Figure 2.1. United States GNP and water withdrawals.

(Source: P. Gleick, 2002)

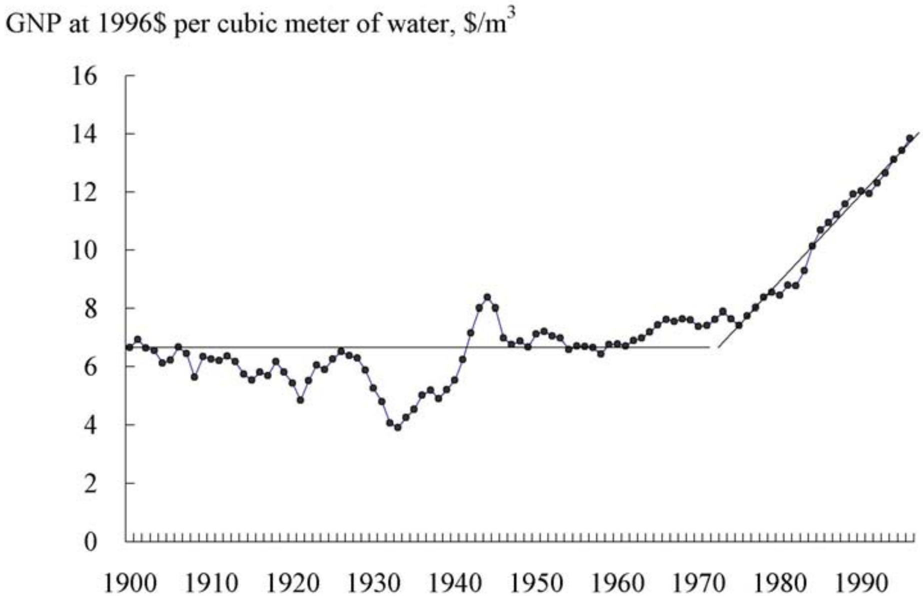


Figure 2.2. Economic productivity of water in United States.

(Source: P. Gleick, 2002)

Figure 2.3 and 2.4 show gross domestic product of Hong Kong, water use, and economic productivity of water. The trend of water use with economics activities is as same as case of U.S. In the first period from 1960s to 1990s, the higher GDP rose, the more water was need. The economic productivity of water in this period is relatively constant at 600 HK$ per cubic meter of water. After 1990s, GDP was still growing but water use was relatively constant. It means that economic productivity rose steadily from 1990s.

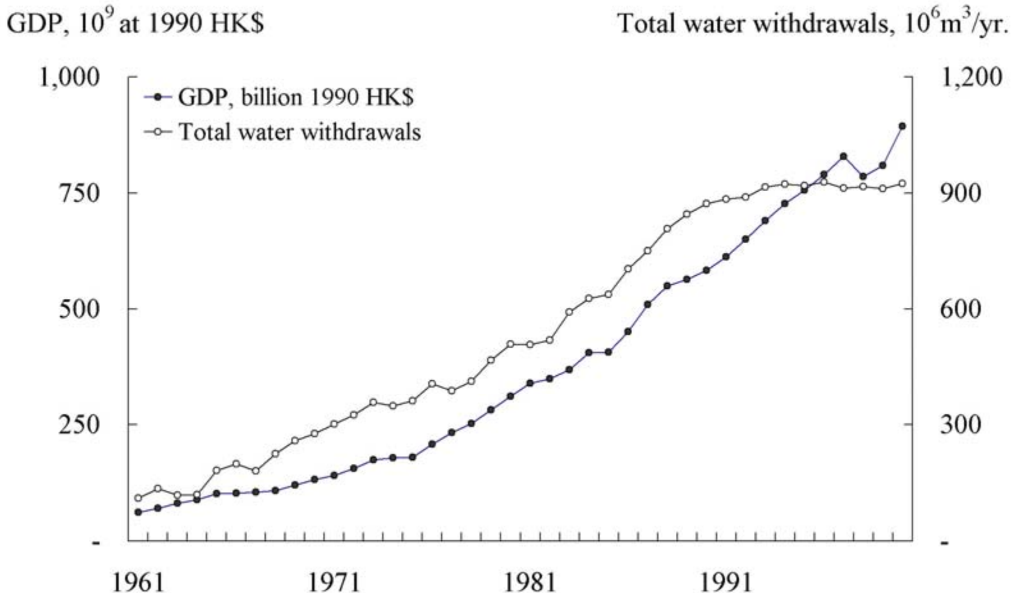


Figure 2.3. Hong Kong GDP and water withdrawals.

(Source: P. Gleick, 2002)

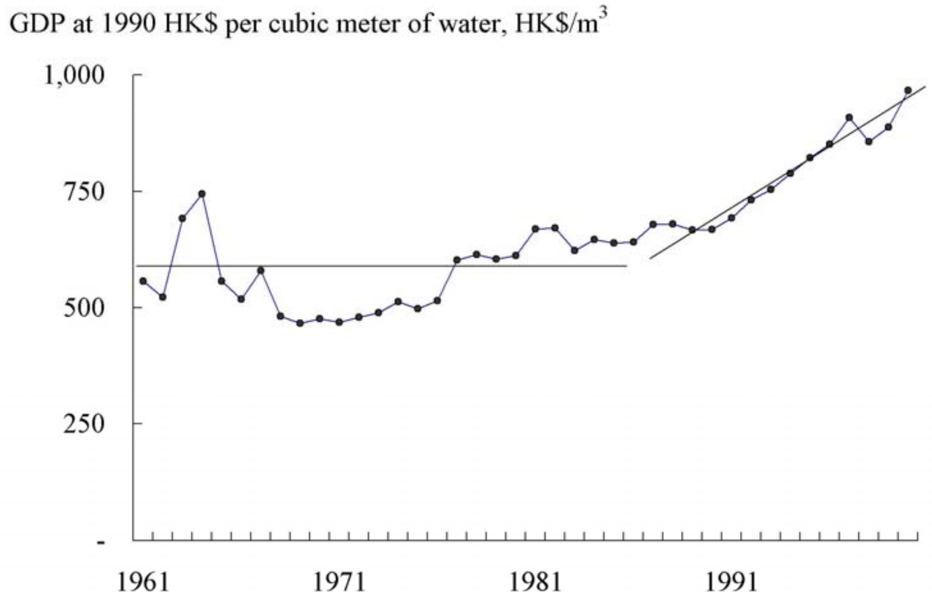


Figure 2.4. Economic productivity of water in Hong Kong.

(Source: P. Gleick, 2002)

Figure 2.5 and 2.6 show GDP index of China, water use, and economic activity of water. As shown in figure 2.5, the trend of water use with economic situation is as same trend as previous cases. Economic productivity of water in China was divided into 2 groups; (1) from 1950s to 1980s, and (2) after 1980s. GDP index per cubic meter in the first group was relatively constant but the second group was steadily increasing.

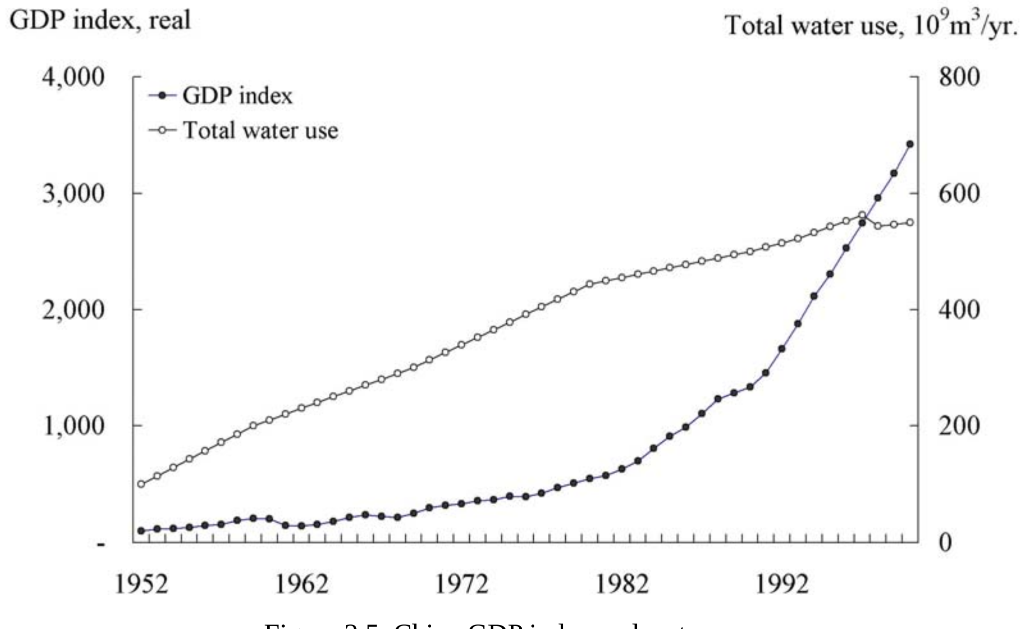


Figure 2.5. China GDP index and water use.

(Source: P. Gleick, 2002)

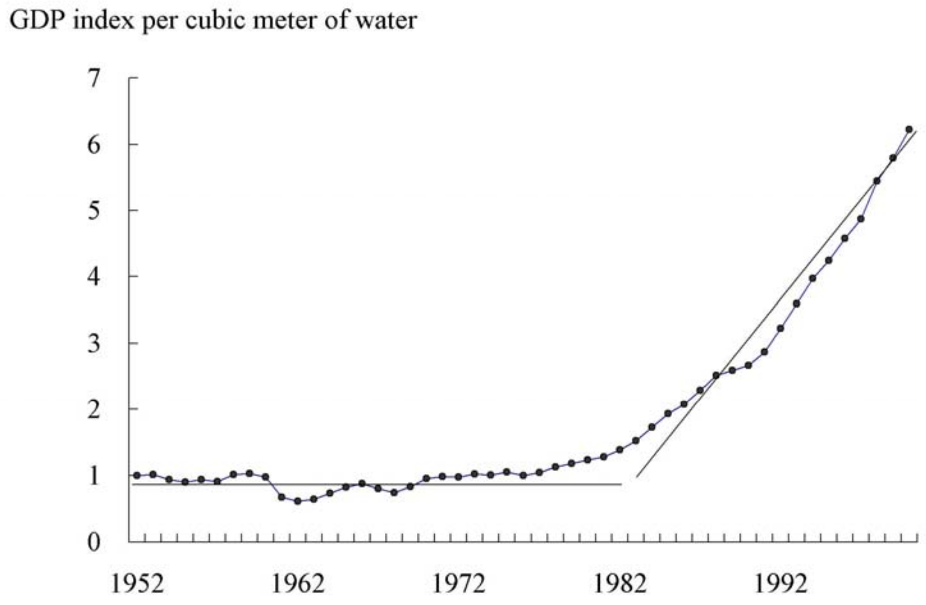


Figure 2.6. Economic productivity of water in China.

（Source: P. Gleick, 2002）

The next interesting example is case of Japan as shown in figure 2.7 and 2.8. Matsushita (2006) concluded the water-related infrastructure building under rapid urbanization of Japan. The history of water infrastructure with economic situations of Japan can be divided into 4 periods.

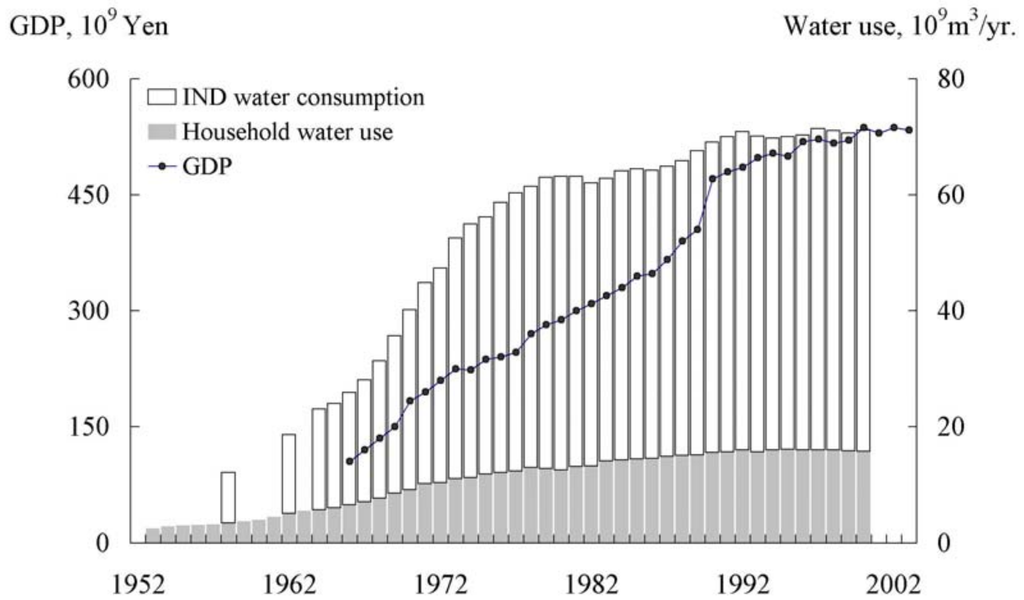


Figure 2.7. Japan GDP and water use.

(Source: http://www.stat.go.jp, http://www.meti.go.jp)

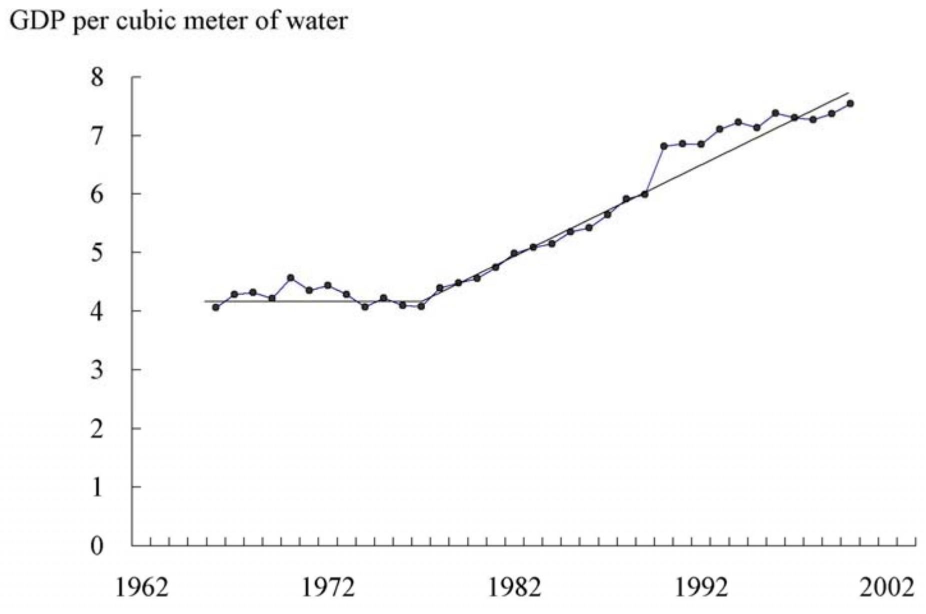


Figure 2.8. Economic productivity of water in Japan.

(Source: http://www.stat.go.jp, http://www.meti.go.jp)

1. Period 1: Economic rebuilding (1940s to 1950s)

   In this period, government concentrated in industrial development promotion policy to reconstruct economics activities after World War 2. In this period, water supply management especially constructing new multi-purposes dams and river works was developed as main infrastructure with transportation system. Industrial water law was declared in 1956 to control and support industrial policy.

2. Period 2: Rapid economic growth (1960s)

   Economics growth rate and water use were rapidly increased in this period. GDP and water use growth rates were the highest until now. The pollution problem was increasing concerned from rapidly increasing industrial production and populations. There are many environmental laws were be enacted in this period as follow; law concerning control of groundwater extraction for building use (1962), basic law for environmental pollution control (1967), and water pollution control law (1970).

3. Period 3: Oil crisis (1970s to 1980s)

   After oil crisis in 1973 and 1979, GDP growth rate was decreasing compared with period 2. In period of oil crisis, the oil price was sharply increased. Central government declared the energy saving policy and environmental prevention as clean production technology and eco system. In this period, pricing policy became a popular measure for water supplier. Not only industrial sector applied clean technology as recycled water in production, but also household sector used treated wastewater recycling systems for own house and rainwater recycling water for large scale projects. From that reasons, the growth rate of water use was gradually increasing. In this period, water pricing policy became a popular measure for water supplier.

4. Period 4: Relatively constant economic growth (1990s to 2000s)
Economics growth rate in this period was gradually increasing again from the beginning of 1990s. Water use increased at the same time and became constant again.

Figure 2.9 and 2.10 show industrial and household water use in Japan from 1952 to 2000. For non-agricultural water use, industrial sector is approximately 3 times of household sector. Now, main source of water for industrial water is recycled water at 80 % of recycled rate. This water saving policy was successful because of the powerful law and effective implementation. For household sector, water use unit is gradually increasing from the beginning of 1980s because of successful wastewater recycling systems and leakage reduction system to 5 % of leakage rate.

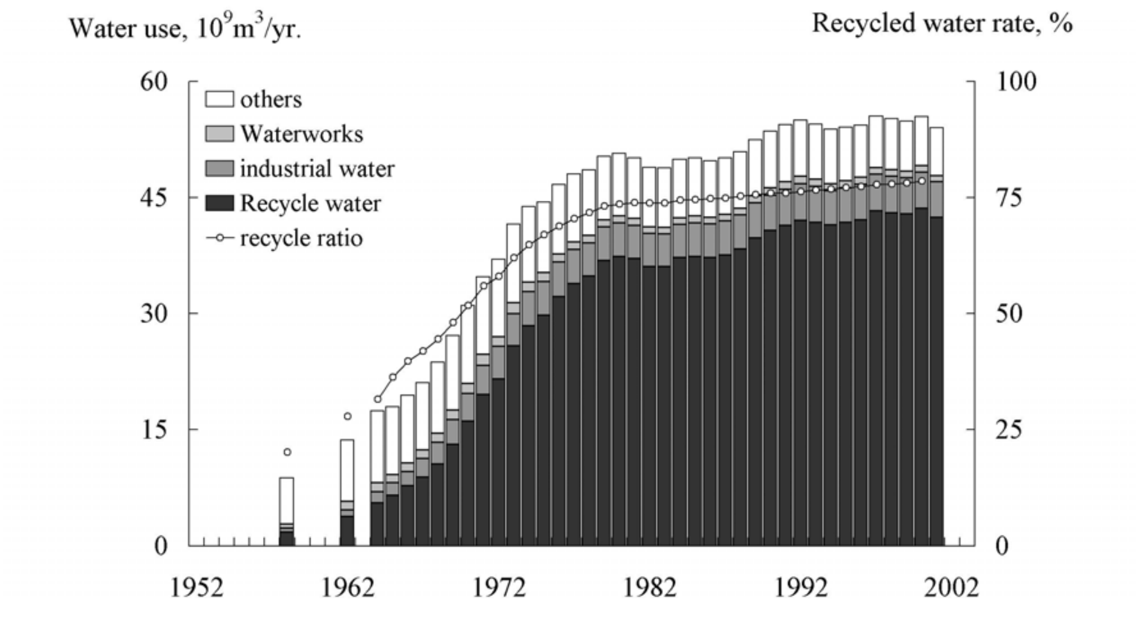


Figure 2.9. Industrial water use in Japan

(Source: http://www.stat.go.jp, http://www.meti.go.jp)

Summary of water use and economic

In this sector, water use was concentrated with economics activity in many national cases. There is a definite possibility that the trend of water use and GDP will be the same if economic productivity is relatively constant. Water use will be constant or gradually decreasing if economic productivity of water rises steadily. It means that the value of GDP is higher than the past with the same unit of water. For example, we have one factory to produce cake. From the past, same production needed same amount of water used in product. However, the cake was recently decorated for higher price. The value added of this cake is higher with constant water use. However, if factory produced more cake, it absolutely needed more production and more water.

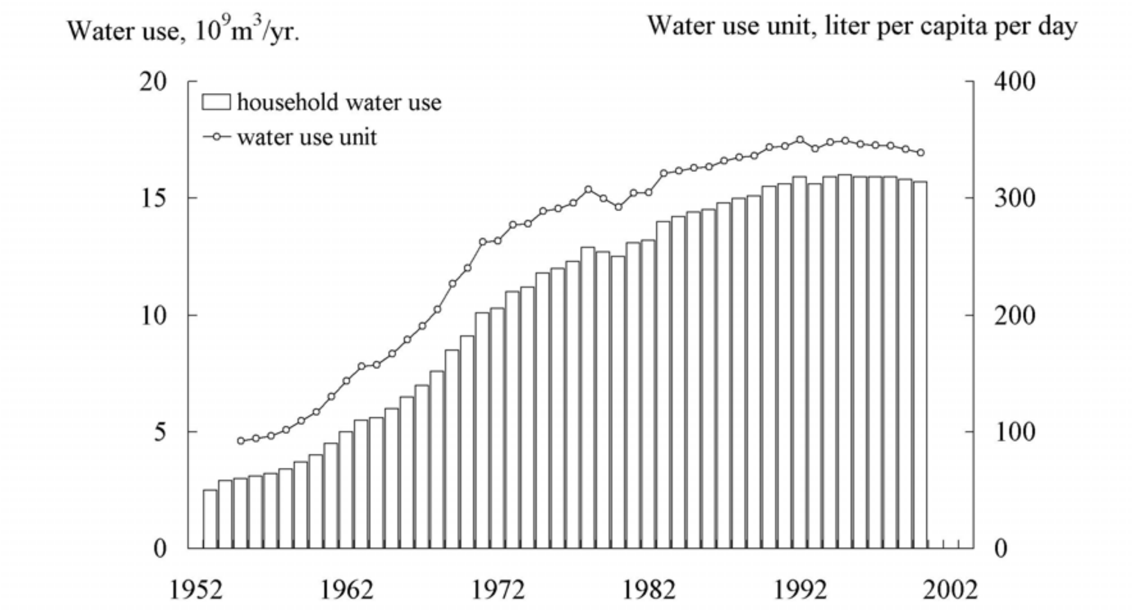


Figure 2.10. Household water use in Japan

(Source: http://www.stat.go.jp, http://www.meti.go.jp)

It doesn't mean that there is no relationship between water use and economic activities but the detail of intermediate transactions or flow of input-output of each production have to be considered with water use. From this reason, Input-output table model with scenarios of declared policy is needed to generate the production with flow of input-output to calculate water use unit per intermediate transactions that is not value added or GDP.

2.2 Industrial water demand

National Economic and Social Development Board (NESDB, 2006) forecasted industrial water demand in the eastern part of Thailand. Industrial water demand was divided by industrial estate area into 2 groups; inside and outside service area of Industrial Estate Authority of Thailand (IEAT).

Water demand in case of inside industrial estate of IEAT was calculate by forecasted factory area and water use unit per area by industrial types. In case of outside service area of IEAT, industrial water demand was calculated by water use per horse power with collected data from questionnaire survey method. The result shows that water demand will be dramatically increasing within next 10 years from 399 to 825 million cubic meters per year or approximately 2.1 times.

Department of Water Resources (2003) forecasted industrial water demand by using production output data form Department of Industrial Works with water use unit per output. Output in the future was forecasted by using trend analysis of gross provincial product in the past. Water use unit used in the model was constant.

Department for International Development of the UK Government (2003) proposed the approach to forecasting industrial water demand and use is to carry out a trend analysis as follows:

- Establish the relationship between industrial production and water use for various sectors;
- Assess the trends in industrial production;
- Project trends in industrial production into the future to establish the future water use.

Gross Domestic Product (GDP) has become a common variable used in demand forecasting models. Past studies in a number of countries have shown that there is a reasonable correlation between GDP and industrial water use. However, no account is taken of the changing nature of industrial production and the effect on water demand and use. For example, in many industrialised countries production has moved away from manufacturing and towards the commercial service sector and this provides different patterns of water use. Technological improvements in industrial production can also lead to significant water savings. For example, in Israel, industrial production increased by 250% while water consumption rose by only 30% owing to regulation and licensing encouraging the use of water saving and re-use technologies.

Chulalongkorn University (2003, 2002, and 1999) forecasted industrial water demand by using gross domestic product of 21 types of industrial sector. This industrial output is function of labor and capital by production function of Cobb-Douglas. 21 industrial types were shown as follow; (1) agricultural simple product, (2) food, (3) beverage, (4) textile, (5) garment, (6) leather , (7) wood product, (8) furniture, (9) paper, (10) printing, (11) chemical, (12) petroleum, (13) rubber, (14) plastic, (15) non-metal, (16) metal, (17) construction product, (18) machine, (19) electronic, (20) transportation,(21) the others. The GDP in the future was calculated with scenarios of 2 economics growth rate as follow; low and medium growth rate. Next, forecasted GDP was analyzed by using regression analysis. The input (labor and capital) in the future was forecasted by trend analysis in provincial scale. Finally, industrial water demand was calculated.

Royal Irrigation Department (2000) forecasted industrial water demand with 2 group of factory as follow; the factory located inside and outside the industrial estate. Industrial water demand of the first group or inside estate was calculated by using trend analysis of gross provincial product in each industrial type with unit water use. Case of outside estate, water demand was calculated by using area and water use unit (17.5 m^3/acre/day). In the future, water demand of factory located outside industrial estate will be constant because there is no expansion plan for estate.

Binnie et al. (1997) forecasted industrial water demand (surface water and groundwater) by using trend analysis of product in each industrial type with water use unit per product.

U.S. Geological Survey (1978) proposed recommended methods for measurement, estimation, and data collection method for industrial water use. The U.S. Army Corps of Engineers' Institute for Water Resources Municipal and Industrial Needs Model (IWR-MAIN model) is an important tool for forecasting changes in industrial use that take into account economic factors. Public-supplied industrial water use is estimated by the model through application of coefficients for water use per employee for large and average-sized establishments to Standard Industrial Classification or SIC codes, number of employees, and an adjustment for price change. Since the model was developed based on economic factors involved in public supplied industrial use, it is not recommended that the coefficients be applied to self-supplied industrial users.

Summary of industrial water demand

Industrial water demand model was generally developed by using product from each industrial type with water use unit analysis. However, forecasted step was analyzed by using trend analysis. The main assumption of trend analysis is the condition in the future is as same as the past. Not only changing economics structure by declared governmental strategy was not calculated, but the changing water use structure was not analyzed also. Without this analysis, Thailand may face the same problem as case of Tokyo in chapter one. From this reasons, changing economics and water use structure have to be analyzed with socio-economic structure by using input-output table model.

2.3 Household water demand

National Economic and Social Development Board (NESDB, 2006) forecasted household water demand in the eastern part of Thailand. Household water demand was divided by service area of pipe water. The first group located in service of Waterworks Authority was calculated by forecasted population data (number of population, migrations, and size of people per family, urbanization, and pipe water master plan with water use unit per capita from metering method. The second group is located outside service area of pipe water. Water use unit in this case is constant at 80 liter per capita per day. The result shows that household water demand will be constantly increasing within next 10 years from 276 to 372 million cubic meters per year or approximately 1.3 times.

Department of Water Resources (2003) forecasted household water demand by using water use unit analysis in different areas as follow; small municipality (no of population is less than 20,000 persons) with water use unit at 120 liter per capita per day (lpcd.), medium municipality (no of population is from 20,000-50,000 persons) with 200 lpcd., and large municipality (no of population is more than 50,000 persons) with 250 lpcd. This water use unit is analyzed data from service area of Provincial Waterworks Authority from past 10 years. The water use unit in rural area is 50 lpcd. from data of Ministry of Interior.

Department for International Development of the UK Government (2003) proposed the method to forecast unmeasured household consumption such as Micro-component analysis, Use of a constant annual per capita demand, and Changes in consumption owing to assumed changes in household size.

Micro-component analysis involves forecasting the future demand for water by assessing the future trends in the underlying elements of water use. It requires forecasts of the following: Water appliance ownership (e.g. washing machines, showers, baths), Frequency of the use of the various water appliances, and the volume of water that is used each time the appliance is used;

The accuracy of a micro-component analysis is dependent on the quality of the baseline data. This method requires large quantities of data and is relatively expensive to implement even for a small sample size.

Chulalongkorn Univeristy (2003, 2002, and 1999) forecasted household water demand by using population model and water use unit analysis. Population model was developed by using component method with program named PEOPLE. The average population growth rate is 0.56 % per year. Water use unit was analyzed by using econometrics with questionnaire survey. Average water use unit in approximately 190 lpcd.

Royal Irrigation Department (2000) forecasted household water demand by dividing people into 2 groups; urban and rural area with 4 periods of project (5, 10, 15, and 20 years). Water demand was calculated from no of population and water use unit as follow; (1) urban area with unit of 150 lpcd, and (2) rural area with unit of 100 lpcd.

Binnie et al. (1997) forecasted household water demand (surface and groundwater) by using population model with water use unit analysis in Tambon (district), Amphor (administration subdivision of province) and province scale. Population in the future was calculated by the past population growth rate. The additional population from tourists and unregistered citizens in Bangkok were calculated by 20 % of registered citizens. The water use unit increased in the future as shown in table 2.1.

Table 2.1. Water use unit per Capita (liter per capita day.)

Area	1996	2006	2016	2026
Bangkok and Amphor Muang in 5 vicinities	250	300	325	350
Outside Amphor Muang in 5 vicinities	200	250	275	300
Amphor Muang outside BKK and vicinities	150	200	250	300
Other areas	100	150	200	250

Source: Binnie et al. (1997)

U.S. Geological Survey (1978) proposed the method to forecast domestic water use by using coefficients of use per person. Reasonable per capita values can be developed by three methods; (1) measuring selected individual household use, (2) reviewing public water-supply or wastewater-collection records of individual household use, or (3) reviewing published reports. Models can be used to adapt regional correlations factors to local conditions or to project future use by assuming what impact changes in water use, such as implementing conservation measures like low-flow toilets, will have on domestic use.

Summary of household water demand

Household water demand was generally forecasted by using population model with water use unit analysis. Population model was calculated by the past statistic data. However, this study area including Bangkok (capital of Thailand) is the central part of political, economic, and education development of Thailand. The main cause of rapidly changing population structure is migration because the birth and death growth rate is relatively constant. Changing number of population from migration is always neglected to calculation with the changing economic structure from declared governmental strategy. It is difficult to calculate without the detail of economics activities. Not only number of migration depends on economic, but water use unit is also changing with changing daily life style form rapid urbanization. From this reasons, population and water use unit have to analyze with socio-economic structure by using input-output table model.

2.4 Agricultural water demand

National Economic and Social Development Board (NESDB, 2006) forecasted agricultural water demand in the eastern part of Thailand. The water demand was divided by service area of Royal Irrigation Department (RID). The first group located in service of RID was calculated by crop area in irrigation master plan and water use unit per area in each main crop. The second group is located in service area of Department of Water Resources. The analysis of this type is as same as the first group. Not only irrigation water demand was forecasted, but livestock water demand was calculated in this step also. The result shows that agricultural water demand will be increasing within next 10 years from 4,461 to 6,922 million cubic meters per year or approximately 1.55 times. Agricultural sector is the main water consumer in this study area approximately 80 % of total water demand.

Department of Water Resources (2003) forecasted irrigation water demand by dividing study area into 2 groups; (1) area inside serviced irrigation area of RID, (2) area outside service area of RID (mainly rainfall). Water use unit per one rai (0.4 acre) is shown in table 2.2.

For livestock water demand, number of livestock collected from Department of Livestock Development with water use unit as follow; (1) pigs, beef and daily cattle, buffalo, goats, and sheep need water 40 liter per capita per day, (2) chicken need 1 lpcd, and (3) duck need 3 lpcd. Forecasting process was developed by using trend analysis of gross provincial product.

Table 2.2. Water use unit of irrigation area

Types	Water use unit; m^3/rai (0.4 acre)
Inside irrigation area of RID	1166-1825
Outside irrigation area of RID	
- Using rain water and water from river or canal	928-972
- Using only rain water	405-721

Source: DWR, 2003

Department for International Development of the UK Government (2003) proposed the method to forecast agricultural water demands are primarily a function of the following: meteorological conditions, crop type, cropped area for each type of crop, type of irrigation method and irrigation efficiencies, and water charges.

For agriculture, the main considerations are rainfall and evaporation rates. As rainfall decreases and/or evaporation rates increase, the irrigation needs are increased. Changes in crop type can have a significant impact on water demands, which may or may not be positive. High value crops such as garden vegetables generally have higher water requirements than, for example, grain crops. Changes in cropped area can be a change in total area, as new land is developed or existing land taken out of production, or it can be a result of changes in crop type, as the area of one type is changed to accommodate changes in another type. Losses and inefficiencies usually account for a significant proportion of total irrigation requirements. Their impact can be improved through various means and the analyst will have to determine the likelihood and magnitude of improvement programs.

Chulalongkorn University (2004 and 2000) forecasted irrigation water demand by using demand for crops in the future with water use unit per crop. Crop demand was analyzed as function of export (function of world GDP and crop price in world market), crop price sold at the field, and cost. The important assumption are as follow; (1) the world economic growth rate is 2 % (effect from 911 and decreasing growth rate of U.S., Japan, and Asia), (2) inflation rate = 1-3 %, (3) crop price in world market depends on price in the past, world economy, and time, (4) domestic crop price depends on price in the past, and price index, and (5) cost depends on the past cost, price index, and world economy. Next, the value of crop (million Thai baht) was transformed to unit of weight (ton or kg.) and crop area (rai, acre) in the final step. Table 2.3 shows water use unit in each crop. The method for estimating irrigation demand is as follow;

Table 2.3. Water use unit in each crop.

Month	ETp	Major rice		Minor rice		Sugarcane		Corn or maize		Cassava	
		FD	Kc	FD	Kc	ET	Kc	ET	Kc	ET	Kc
Jan	2.95			9017	1.23	2974	0.63				
Feb	3.67			8250	0.86	3053	0.52			4698	0.80
Mar	4.45			11228	1.13					9042	1.27
Apr	4.10			12728	1.45					7216	1.10
May	4.28			11640	1.23	4452	0.65			4794	0.70
Jun	3.80			8425	0.86	5229	0.86	4803	0.79		
Jul	3.97					7178	1.13	11751	1.85		
Aug	3.41	9352	1.13			7366	1.35	4692	0.86		
Sep	3.98	12550	1.45			9934	1.56	7833	1.23		
Oct	3.41	9925	1.23			7038	1.29				
Nov	3.22	7631	0.86			6182	1.20				
Dec	2.87					4271	0.93				
Mm/d.	Average	9839		10021		5768		7270		6437	

Source: CU, 2000, Note: Unit of FD and ET is mm./day/rai

1. Water use unit of sugarcane and corn was calculated by using following formula; ET = ETp*Kc, Where ET = crop water requirement, ETp = reference crop evapotranspiration for grass, Kc = crop coefficient.

2. Water use unit of rice was calculated by using following formula; FD = ET-ER+DP, where FD = water requirement of rice in the filed, ET = water requirement of rice, ER = effective rainfall, DP = groundwater contribution.

Royal Irrigation Department (2000) forecasted irrigation water demand by assumption of decreasing crop area in the future analyzed from the past data. Water use unit per crop was calculated by using Penman-Monteith formula that recommended by the Food and Agricultural Organization (FOA) of the United Nations as the sole method for the reference crop evapotranspiration, however, the disadvantage of this method is requirement of reasonable quantity of climatic data.

Summary of agricultural water demand

Agricultural water demand was divided into 2 groups; irrigation and livestock sector. Irrigation water demand consists of crop area and water use unit analysis. Varying Crop area depends on variation of price and economics situation. In some year, crop area in Chao Phraya River Basin is more than the target plan of government calculated from existing water in big dams of the northern part. It means that citizen consider to plant by mainly considering from demand driven as follow; land use change, crop price, cost, and production factor. However, past irrigation water demands were not considered with the impacts from declared strategy such as industrial cluster plan. From this declared policy, food and beverage is the target groups that were specially concentrated. This expansion needs raw material from agricultural side; however, the question is how to forecast the impact under condition of changing economics structure.

2.5 Summary

From the past water demand management in each sector, there are questions as follow;

1. Is the structure of water use suitable with the socio-economic structure?
   - What are the impacts from declared governmental policy as follow?
     - Internal effects: National economic and social development plan, law and regulation and etc.
     - External effects: international agreements with other countries such as Free Trade Agreements (FTA) and etc.
   - What is the suitable decision to declare policy with water constraints in study area?
     - With/without new water infrastructure.
   - How can pricing policy apply with water user in each sector? Who pay higher cost resulted from new water infrastructure cost or difficulty to get more water in future?
     - Subsidy by government or pay by water users.
2. How to manage the water share of each user and activity with the changing

economics structure from declared policy?

Governmental side should know about the impact from declared strategy to change water use structure with constraints of each water source. However, this changed structure of water will affect to change the economics structure again as dynamic cycle. From that reason, water demand management model should be developed as toolbox including economic and engineering with scenarios and risk analysis for policy makers to make decision about declared governmental policy.

Chapter 3

Thailand and Provincial Input-Output Table Model

3.1 Introduction

Wassily Leontief firstly developed Input-output (I/O) analysis with the I/O tables of the United States for the years 1919 and 1929 which were published in 1936. The input-output table shown the interrelationship among various producers of an economy, the production structure of each economics activities in national accounts, flow of input and output of productions, using the intermediate transactions to produce final goods, and consuming the resources in the process of investment import and export (UN, 1999).

Firstly, United Nations (UN) developed the method to implement the System of National Accounts (SNA) in 1953. The developed method was revised again in 1968 by the UN jointly with other international organizations including the International Monetary Fund (IMF), the Organization for Economic Cooperation and Development (OECD), the World Bank and the Statistical Office of the European Communities (EUROSTAT).

In 1993, the United Nations Economic and Social Council recommended that Member States consider using the United Nations System of National Account 1993 (UNSNA 1993) as the international standard for the compilation of national accounts statistics to promote the integration of economic and related statistics, as an analytical tool, and in the international reporting of comparable national accounting data.

In Thailand, the Nation Economic and Social Development Board (NESDB) takes responsibility of constructing National Account since 1950, flow of funds accounts and input-output tables since 1975. The construction of benchmark input-output (I-O) tables is undertaken only once every three to five years. Most of data used in this research was collected from NESDB.

In this chapter, Thailand input-output table model was developed to generate the missing I-O tables for every calendar year from 1995 to 2005. The generated tables were transformed again in the provincial scale to demonstrate the economic structure and interrelationship among various producers of each province in the study area.

Finally, the generated I-O tables were applied with water demand and supply model in other sections by policy scenarios and strategies.

3.1.1 The advantage and disadvantage of IO table

I-O tables have three advantages that make them particularly well suited to analyze structural change (UN, 1999).

1. The data are usually comprehensive and consistent. By their nature, input-output tables encompass all the formal market place activity that occurs in an economy, including the service sector which is frequently poorly represented. For some countries, over a hundred different data sources are used to ensure the completeness and internal consistency of the data (180 row with 180 column of economics activities in case of Thailand), making it probably the single most comprehensive and complete source for economic data for most countries. **Consequently, input-output tables frequently play a fundamental role in the construction of the national accounts.** This role means that the data are thoroughly checked for their accuracy, and that the tables are intrinsically linked with many of the traditional indicators of economic performance such as production and GNP

2. The nature of I-O analysis makes it possible to analyze the economy as an interconnected system of industries that directly and indirectly affect one another, tracing structural changes back through industrial interconnections. This is especially important as production processes become increasingly complex, requiring the interaction of many different businesses at the various stages of a product's processing. **I-O techniques trace these linkages from the raw material stage to the sale of the product as a final finished good.** This allows the decomposition analysis to account for the fact that a decline in domestic demand for autos not only affects the auto industry, but also its suppliers like the steel industry and the steel suppliers like the coal industry and so on. In analyzing an economy's reaction to changes in the economic environment, the ability to capture the indirect effects of a change is a unique strength of I-O analysis.

3. The design of I-O tables allows a decomposition of structural change which identifies the sources of change as well as the direction and magnitude of change. Most importantly, an I-O based analysis of structural change allows the introduction of a variable which describes changes in producer's recipes - that is, the way in which industries are linked to one another, in I-O language, called the "technology"

of the economy. It enables changes in output to be linked with underlying changes in factors such as exports, imports, domestic final demand as well as technology. This permits a consistent estimation of the relative importance of these factors in generating output and employment growth. In a general sense, **the I-O technique allows insight into how macroeconomic phenomena such as shifts in trade or changes in domestic demand correspond to microeconomic changes as industries respond to changing economic conditions.**

Although the field is widely practiced today, problems such as those Leontief encountered, still exist. The limitations of the input-output approach are:

1. The basic input-output analysis assumes constant returns to scale. The input-output model assumes that the same relative mix of inputs will be used by an industry to create output regardless of quantity.

2. Each industry is assumed to produce only one type of product. For example, the automobile industry produces only cars. The distribution and sale of this product is fixed.

3. Each product within the industry is assumed to be the same. Also, there is no substitution between inputs. The output of each sector is produced with a unique set of inputs.

4. **Technical coefficients are assumed to be fixed**: that is, the amount of each input necessary to produce one unit of each output is constant. The amount of input purchased by a sector is determined solely on the level of output. No consideration is made to price effects, changing technology or economies of scale.

5. It is assumed that **there are no constraints on resources**. Supply is infinite and perfectly elastic.

6. It is assumed that all local resources are efficiently employed. There is l no underemployment of resources.

7. Timeliness of input-output data. There is a long time lag between the collection of data and the availability of the input-output tables. The sporadic nature of input-output tables means that continuous time series are impossible to construct without estimating input-output tables for the years between benchmarks. In effect,

input-output tables provide a snapshot of the complete economy and all of its industrial interconnections at one time.

Constructing input-output table needs high budget to collect data in each economics activity. From that reason, the main problem of developing countries is limited budget to survey in small details of each activity. In case of Thailand, only national input-output table was generally constructed in every 5 years; publishing in year 1998 is special case after economic crisis. From this reason, Thailand input-output table model was developed to fulfill the data in uncompleted year without I/O table. Next, provincial input-output table was developed by using developed Thailand I/O table.

3.1.2 Calculation of IO table

As will become clear, I-O analysis emphasizes general equilibrium phenomena. It seeks to take account of production plans and activities of many industries which constitute an economy. This interdependence arises out of the fact that each industry employs the outputs of other industries as its raw material. Its output, in turn, is used by other industries as a productive factor.

Each row of the I-O table shows, in detail, the receipts of an industry from other sectors of the economy. This table is known as the transactions table. As we move across the table, we move from the sales to processing sectors and shipments to the final far right hand cell of final demand sectors such as consumers, investors, governments or foreign countries. It is assumed that this flow across the sectors is a fixed and constant proportion of the amount of the product being produced. I-O tables used in practice are generally constructed in thousand baht terms.

Thai IO table

Nation Economic and Social Development Board (NESDB) constructed Thailand I-O table by using the method of United Nations System of National Account. The details of Thailand I-O table were shown in table 3.1 and table 3.2 as follow. Table 3.2 below shows an example of Thailand I-O table developed by NESDB.

Table 3.1 Thailand Input-Output sector classification

I/O code	Description	I/O code	Description
001	Paddy	036	Fluorite Ore
002	Maize	037	Natural Chemical & Fertilizer
003	Other Cereals	038	Salt
004	Cassava	039	Limestone
005	Other Root Crops	040	Stone Quarrying
006	Beans and Nuts	041	Other Mining & Quarrying
007	Vegetables	042	Slaughtering
008	Fruits	043	Canning & Preserving Of Meat
009	Sugar Cane	044	Dairy Products
010	Coconut	045	Canning & Preserving Of Fruits & Vegetables
011	Palm Nut And Oil Palm And Oil Palm	046	Canning & Preserving Of Fish & Seafood
012	Kenaf And Jute	047	Coconut and Palm Oil
013	Crops for Textile and Matting	048	Other Vegetable & Animal Oils
014	Tobacco	049	Rice Milling
015	Coffee and Tea	050	Flour & Sagu Mild Products & Tapioca Milling
016	Rubber	051	Grinding Corn
017	Other Agricultural Products	052	Flour & Other Grain Milling
018	Cattle And Buffalo	053	Bakery And Other
019	Swine	054	Noodle & Similar Products
020	Other Livestock	055	Sugar Refineries
021	Poultry	056	Confectionery & Snack
022	Poultry Products	057	Ice
023	Silk Farming	058	Monosodium Glutamate
024	Agricultural Services	059	Coffee & Cocoa & Tea Processing
025	Logging	060	Other Food Products
026	Charcoal and Firewood	061	Fish Meal & Animal Feed
027	Other Forestry Products	062	Distilling & Blending Of Spirit
028	Ocean And Coastal Fishing	063	Breweries
029	Inland Water Fishing	064	Soft Drinks & Carbonated Water
030	Coal And Lignite	065	Tobacco Processing
031	Crude Oil & Natural Gas	066	Tobacco Products
032	Iron Ore	067	Spinning
033	Tin Ore	068	Weaving
034	Tungsten Ore	069	Textile Bleaching, Printing & Finishing
035	Other Non-Ferrous Metal Ore	070	Made-Up Textile Goods

Table 3.1 Thailand Input-Output sector classification (cont'd)

I/O code	Description	I/O code	Description
071	Knitting	106	Secondary Steel Products
072	Wearing Apparels	107	Non-Ferrous Metal
073	Carpets And Rugs	108	Cutlery And Hand Tools
074	Jute Mill Products	109	Metal Furniture & Fixture
075	Tannery And Leather Finishing	110	Structural Metal Products
076	Leather Products	111	Other Fabricated Metal Products
077	Foot Wear, Except Of Rubber	112	Engine And Turbine
078	Saw Mill & Wooden Construction Materials	113	Agricultural Machinery & Equipment
079	Wood And Cork Products	114	Wood & Metal Working Machine
080	Wooden Furniture & Fixture	115	Special Industrial Machinery
081	Paper And Paper Board	116	Office Equipment & Machinery
082	Paper & Paperboard Products	117	Electrical Industrial Machinery & Appliances
083	Printing & Publishing	118	Radio, Television, Communication Equipment
084	Basic Chemicals	119	Others Electric Appliances
085	Fertilizer, Pesticide And Insecticide	120	Insulated Wire And Cable
086	Petrochemical Products	121	Electric Accumulator & Battery
087	Paint	122	Other Electrical Apparatuses & Supplies
088	Drug And Medicine	123	Ship Building
089	Soap & Cleaning Preparations	124	Railway Equipment
090	Cosmetic	125	Motor Vehicle
091	Matches	126	Motorcycle & Bicycle & Other Carriages
092	Other Chemical Products	127	Repairing Of Vehicle
093	Petroleum Refinery & Gas Separated Plant	128	Aircraft
094	Other Coal & Petroleum Products	129	Scientific Equipments
095	Rubber Sheet & Block Rubber	130	Photographic & Optical Goods
096	Types And Tubes	131	Watches And Clocks
097	Other Rubber Products	132	Jewelry & Related Articles
098	Plastic Wares	133	Recreational & Athletic Equipment
099	Ceramic And Earthen Wares	134	Other Manufacturing Goods
100	Glass & Glass Products	135	Electricity
101	Structural Clay Products	136	Pipe Line
102	Cement	137	Water Supply System
103	Concrete And Cement Products	138	Residential Building Construction
104	Other Non-Metallic Products	139	Non-Residential Build Construction
105	Iron And Steel	140	Public Works For Agriculture & Forestry

Table 3.1 Thailand Input-Output sector classification (cont'd)

I/O code	Description	I/O code	Description
141	Non-Agricultural Public Works	176	Amusement & Recreation
142	Construction Of Electric Plant	177	Repairing, Not Elsewhere Classified
143	Construction Of Communication Facilities	178	Personal Services
144	Other Constructions	180	Unclassified
145	Wholesale Trade	190	Total Intermedite Transaction
146	Retail Trade	201	Wages and Salaries
147	Restaurant & Drinking Place	202	Operating Surplus
148	Hotel And Lodging Place	203	Depreciation
149	Railways	204	Indirect Taxes less Subsidies
150	Route & Non route of Road Passenger Transport	209	Total Value Added
151	Road Freight Transport	210	Control Total
152	Land Transport Supporting Services	301	Private Consumption Expenditure
153	Ocean Transport	302	Government Consumption Expenditure
154	Coastal & Inland Water Transport	303	Gross Fixed Capital Formation
155	Water Transport Services	304	Increase in Stock
156	Air Transport	305	Exports (F.O.B.)
157	Other Services	306	Special Exports
158	Silo And Warehouse	309	Total Final Demand
159	Post And Telecommunication	310	Total Demand
160	Banking Service	401	Imports (C.I.F.)
161	Life Insurance Service	402	Import Tax
162	Other Insurance Service	403	Import Duty
163	Real-estate	404	Special Imports
164	Business Service	409	Total Imports
165	Public Administration	501	Wholesale Trade Margin
166	Sanitary & Similar Services	502	Retail Trade Margin
167	Education	503	Transportation Cost
168	Research	509	Total Margin and Transportation Cost
169	Hospital	600	Control Total
170	Business & Labor Associations	700	Total Supply
171	Other Community Services		
172	Motion Picture Production		
173	Movie Theater		
174	Radio, Television & Related Services		
175	Library And Museum		

Source: Nation Economic and Social Development Board (NESDB)

Table 3.2 Formation of Thailand Input-Output table

		Agri	Ind	Ser	Total						
	I/Ocode	001-029	030-134	135-180	190	301-309	310	401-409	501-509	600	700
Agri	001-029	Intermediate transaction				Final demand	Total demand	Total import	Total Margin Tran-cost	Control Total	Total Supply
Ind	030-134										
Ser	135-180										
Total	190	Sum (001-180)									
	201-209	Value added									
	210	Control total (190+209)									

Source: Nation Economic and Social Development Board (NESDB)

Note: Agri. = Agricultural sector, Ind = Industrial sector, Ser = Service sector.

Source and status of data

Most economics data was collected from Nation Economic and Social Development Board (NESDB). Table 3.3 shows status of I-O table data. Every 5 year of Thailand I-O table data is complete. Case of year 1998 is specially produced because of economics crisis. Thailand and provincial gross product were published every year in form of National Accounts. Status of provincial I-O table shown in table 3.3 is incomplete in every year. Because of lack of data, Thailand and provincial I-O table model in grey area shown in table 3.3 were developed to analyze changing economics structure from declared governmental strategy.

Table 3.3 Status of I-O table data.

Status of data	1985	..	1990	..	1995	1996	1997	1998	1999	2000	2001	2002	..
Thailand I/O table	O		O		O			O		O			
Thailand GDP	O	O	O	O	O	O	O	O	O	O	O	O	O
Provincial GDP	O	O	O	O	O	O	O	O	O	O	O	O	O
Provincial I/O table													

Source: NESDB

Note: O = data available, ▢ = No data

3.2 Model Structure

3.2.1 Methodology

This section shows the main idea and method of Thailand and provincial I-O table

Model. The model was developed by using the RAS techniques.

The updating process was carried out on the assumption that I-O coefficients change through area and time as a result of three factors; (1) changes in price, (2) changes in the degree of substitution, and (3) changes in the degree of fabrication (UN, 1999).

Based on these assumptions, two dimensions, area and time, were applied to create new I-O tables.

1. The general estimation methodology of area dimension consisted of two successive operations. First, the latest available base-year (2000) input coefficients were adjusted to account for changes of outputs and inputs between Thailand scale and provincial scale. These price-adjusted coefficients were then subjected to the modified RAS iterative procedure to account for possible shifts in production and demand structures from Thailand scale to provincial scale.

2. For the methodology of time dimension, the available I-O tables; 1975, 1980 1985, 1990, 1998, and 2000 were subjected to the modified RAS procedure to account for possible shifts in production and demand structures for calendar year from 1976 to 2005.

The next interesting topic is to apply declared governmental policy and constraints in national, regional, and provincial scale into I-O table as shown in figure 3.1.

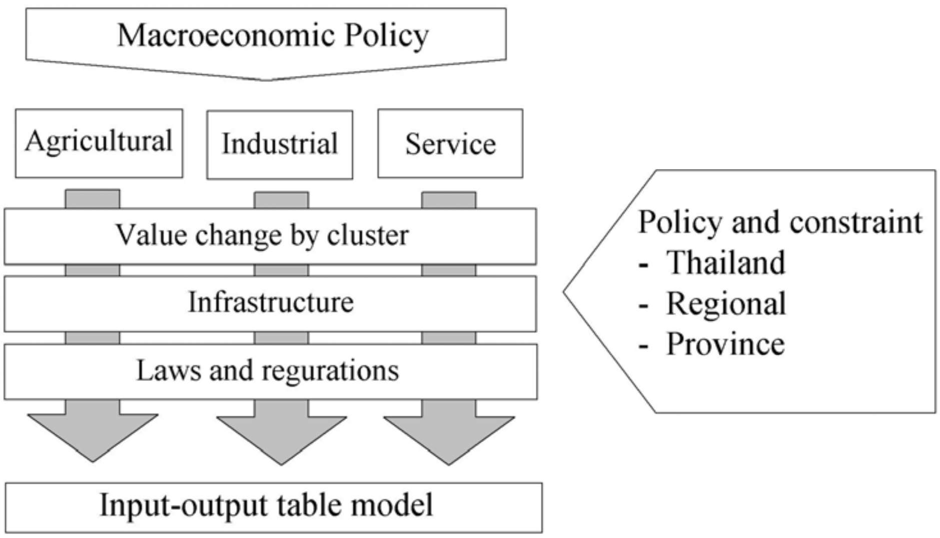


Figure 3.1. Mechanism of applying policy and constraint in I-O table.

3.2.2 The RAS technique

The RAS technique is widely used to update input-output tables on the basis of the benchmark tables compiled with detailed census and survey data. The widespread use of the techniques is explained because in most countries it takes two to five years (5 years in case of Thailand) after the end of the year before the input-output tables for that year can be prepared and published. If the tables are to be used in current analysis, it is important to check whether and to what extent the coefficients have changed since the year to which they relate. By incorporating the most up-to-date information, the RAS technique is used to carry out this check and update those coefficients that are clearly changed in view of the newly available information (UN, 1999).

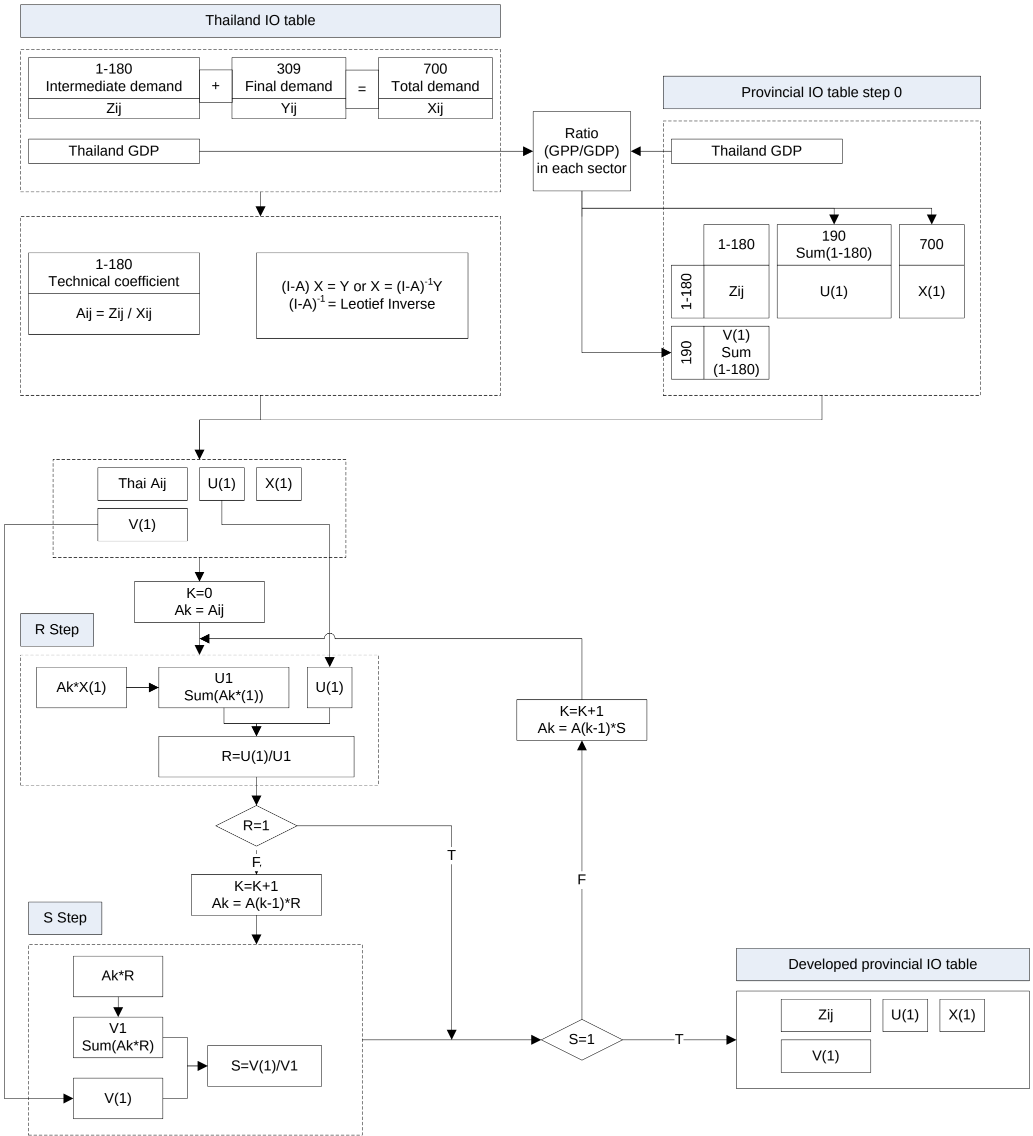


Figure 3.2 Schematic diagram of Thailand and Provincial I-O table model.

Thailand and provincial I-O table in incomplete data year were generated by using the RAS technique. The target of GDP and GPP with declared strategy in national, region, and provincial scale were updated to the existing I/O table. Mechanism of RAS technique using in this research was shown in figure 3.2 (see detail in United Nations (1999), *Handbook of Input-Output Table Compilation and Analysis*).

3.3 Model formulation

From the previous topics, Thailand and Provincial I-O table model with scenarios of declared governmental options were developed by using GAMs language. This developed model is the first step of water demand management model and analyzed data will be the important input to other models. The schematic diagram of I-O table model was shown in figure 3.3.

3.3.1 Model scenarios

Changing economics activity from declared policy was calculated from developed input-output (IO) table. Three economic scenarios generated in this step are normal growth rate case, internal effects from master plan of Thai industrial cluster (SUTTINON, P., 2006)., and external effects from free trade agreements (FTAs) with international partners. Economic scenarios simulated in this step were shown in Table 3.4.

Table 3.4. Economics scenarios in input-output table model.

case	Average growth rate	Internal effect	External effect or FTAs with partners	
			The global	U.S.A., JP, and CN
Case 1	O			
Case 2	O	O		
Case 3	O	O	O	
Case 4	O	O		O

Note: U.S.A. is the United States of America, JP is Japan, and CN is China.

First, economic growth rate of industrial, agricultural, and service sector was separately analyzed by using average growth of last 20 years from 1984 to 2004. The analyzed industrial growth rate in normal case was 8.2%.

Second, internal effect of economic scenario or Thai industrial cluster strategy was generated from the 9th and 10th national economic and social development plan of National Economic and Social Development Board (NESDB, 2005) and industrial master plan of Office of Industrial Economics (OIE, 2005). The main target of this policy was focused on industrial types of food, garment, electronic goods, and automobile.

Third, external effect of economic scenario or changing Thailand industrial market share was analyzed by focusing on the future plan of government agencies related to control industrial policy and possibility of movement of production base from the effect of declared policy and the world situations in free trade agreements or FTAs with international partner. Two main groups of partner were selected to simulate the external effect. The first one is FTAs with the global and the second is FTAs with the United States, Japan and China (OIE, 2005).

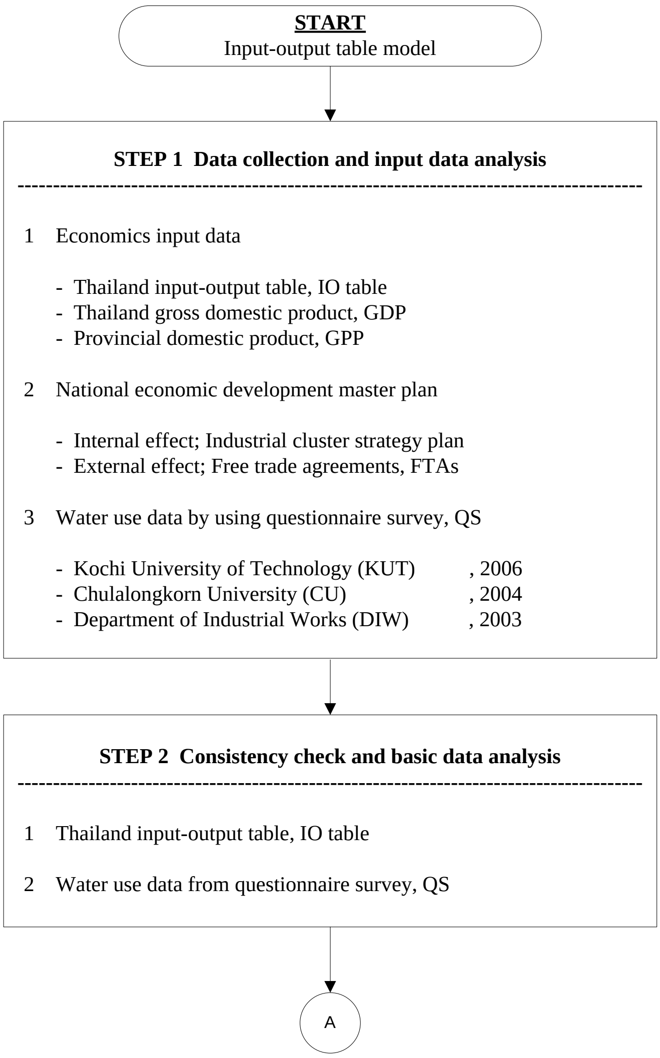


Figure 3.3. Schematic diagram of input-output table model

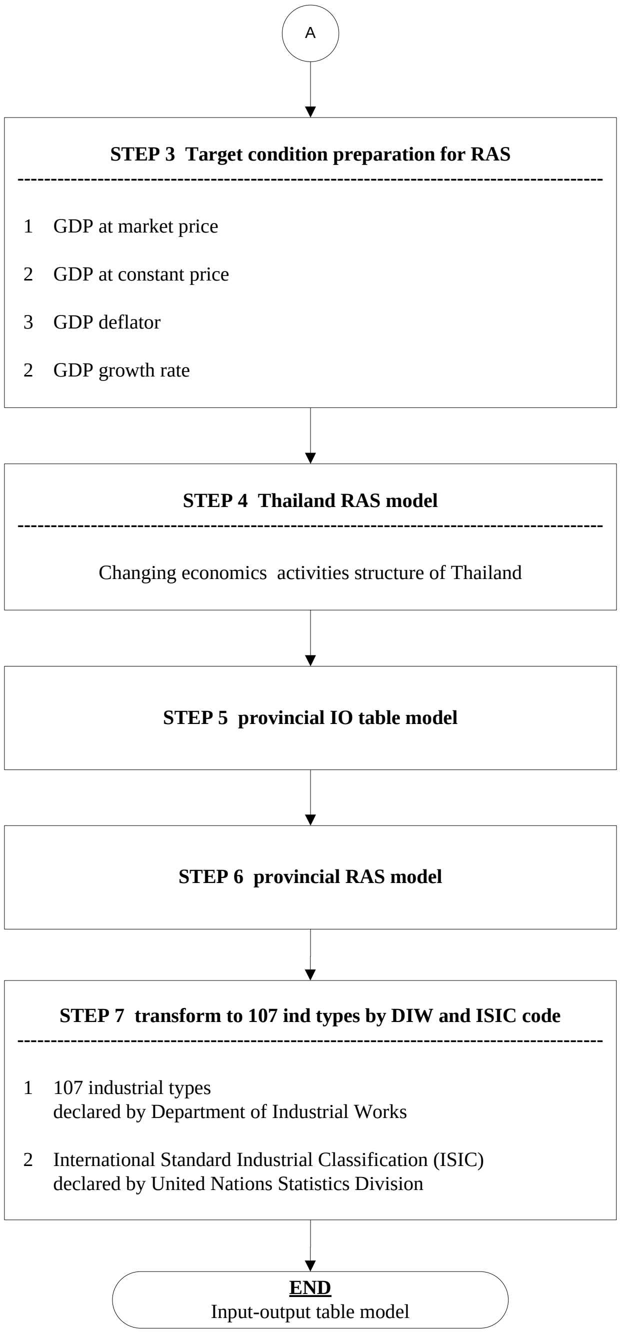


Figure 3.3. Schematic diagram of input-output table model (Cont'd)

3.4 Summary

Provincial input-output tables with economics scenarios in study area were developed by using RAS technique. This developed I-O tables in province scale are the important input for industrial, household, and agricultural water demand management in the next part. An increase in demand of output resulted from declared policies is likely to cause a rise in need of infrastructure especially water in production and utility process of industrial sector, higher water use unit of household water demand, and higher crop area and productivity of agricultural sector.

One important limitation of developed provincial I/O table model is that the structure of each sector in provincial scale is similar as Thailand scale. The reason is there is no data of provincial I/O table. The developed I/O tables in each province were forecast by using ratio of gross provincial product (GPP) and gross domestic product (GDP) in separately agricultural, industrial and service sector. However, National Economic and Social Development Board (NESDB) planned a new project to collect detailed data of GPP. Form this project; Provincial I/O table will be generated more accurately. (Now, the state of project is under developing, Nov, 2007, http://www.nesdb.go.th/)

Chapter 4

Industrial Water Demand Model

4.1 Introduction

Lower Chao Phraya River Basin (LCPRB) shown in figure 1 is one of the important areas of development in economic and industrial sector of Thailand. This area can produce 46 % of Gross Domestic Product (GDP) in Thailand which industrial Gross Domestic Product or GDP is the main part with 44 % of GDP share from high density of factories in this study area. In the 9^{th} and 10^{th} national economic and social development plan with Thai industrial master plan, Thai government concentrates to develop industrial activities by declared industrial cluster strategy master plan and free trade agreements with other countries (NESDB, 2005 and OIE, 2005).

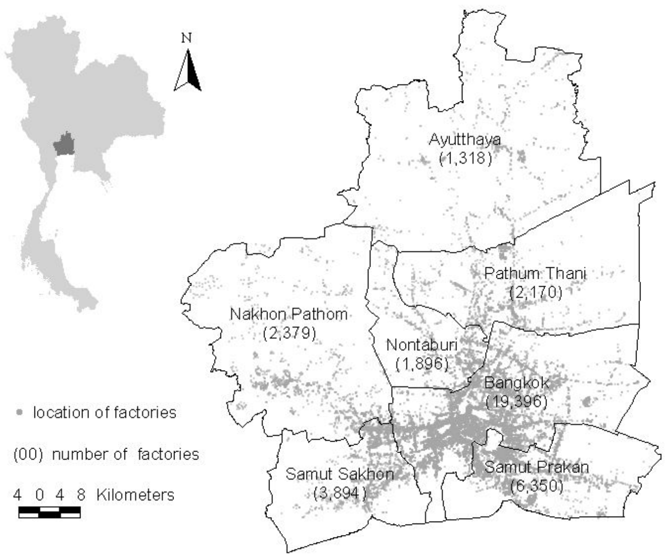


Figure 4.1. Study area and scatter of factories.

(Source: DIW and NESDB.)

An increase in demand of output resulted from declared policies is likely to cause a rise in need of infrastructure especially water in production and utility process; However, there are constraints of groundwater use controlling policy to protect land subsidence’s problem in this study area. It is possible that previous policies will result in conflicts between the economic and environmental viewpoint.

From those interesting topics, policy maker needs a toolbox for industrial water management systems that not only considering separately supply or demand side, but also integrating water management system with concerning about effects to economic, environment, and society. Governmental side has to know how water use structure change from changing economic structure resulted from declared governmental strategy with water constraints in service area. Is that target of concentrated industrial types possible with limitation of water sources; if it is not possible, how to manage it? We have many choices such as; to decrease the target of industrial GDP, to find more water supplies to support higher need, to decrease water demand to water yield point, or combination of some choices.

Another interesting topic is choosing the proper policy that keeps maximum benefit of both factory side and governmental side by using pricing policy. However, there are many uncertainties of water demand in the future such as high, medium or low water demand growth rate. If high water demand occur with infrastructure supported medium growth, it is possible to have damage from water shortage. If the water demand growth rate is low with huge dam, there are losses from construction, maintenance and operation costs.

There are four main objectives in this chapter as follow;

1. To develop water demand model by using input-output table model with impacts from changing economic structure and water use unit analysis.

2. To analyze water demand-supply curve to calculate impacts from pricing policy from secondary data of government agencies and questionnaire survey including constraints of each water source in each province and effects of recycled water measure.

3. To develop integrated water management model including government option scenarios; with/without new water infrastructure, and case of with/without subsidy from governmental side to select the optimum scenario for policy maker to make decision with water demand management system by using equilibrium analysis, pricing policy, and cost-benefit analysis by each evaluation standard.

4. To develop strategic decision making system for uncertainly (high, medium, and low water demand growth) of infrastructure investment (to construct all infrastructure in the starting point, step by step, or do nothing) in the future.

4.2 Model Structure and Formulation

The schematic diagram of industrial water demand and management model developed by using GAMs language is shown in Figure 4.2. The model was divided into four models; water demand, water supply, integrated water management, and strategic decision making model.

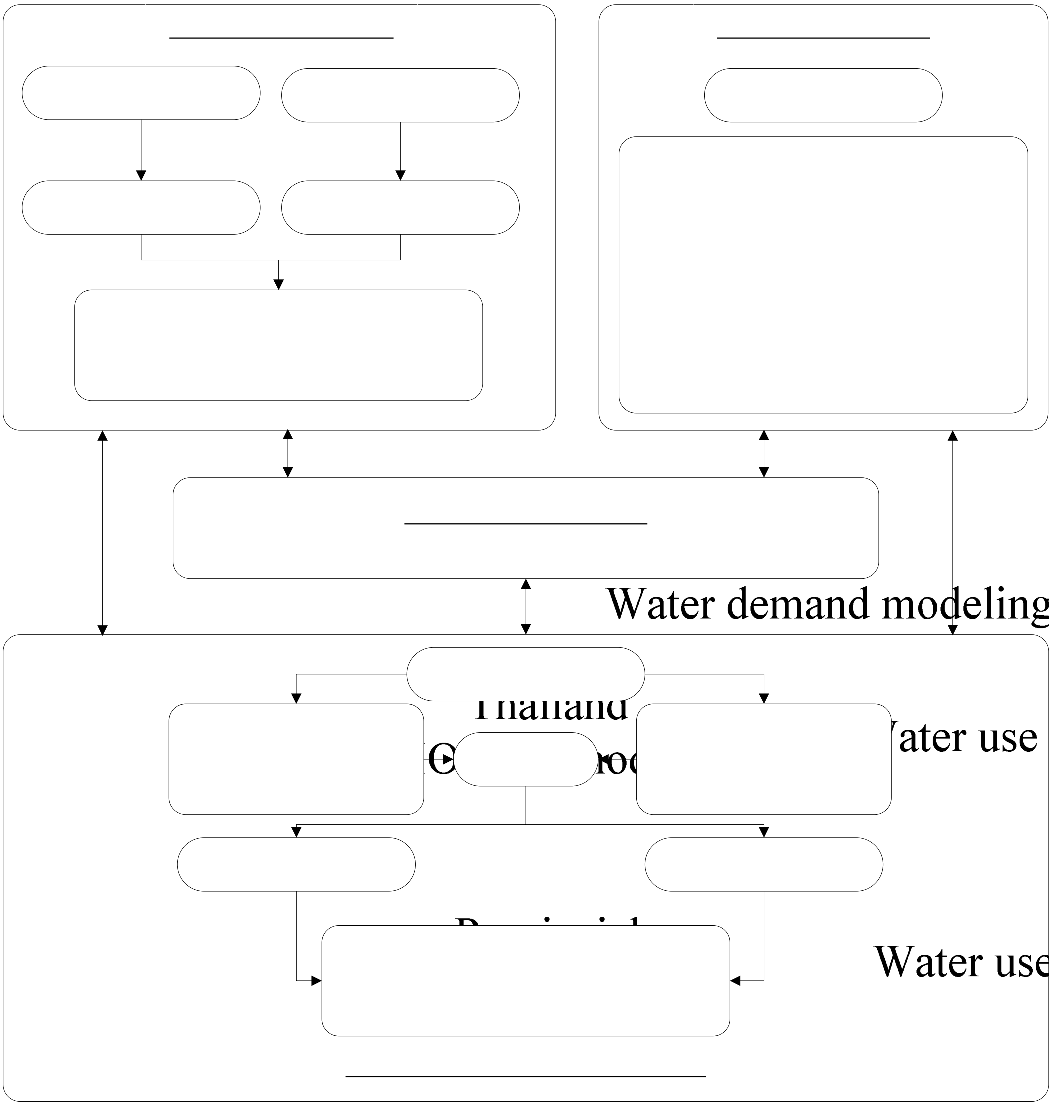


Figure 4.2. Schematic diagram of industrial water demand.

4.2.1 Water demand model

Firstly, water demand in each province and industrial activity was calculated from intermediate transactions of input-output (IO) table and water use unit analysis. Three economic scenarios generated in this step are normal growth rate case, internal effects from master plan of Thai industrial cluster (SUTTINON, P., 2006)., and external effects from free trade agreements (FTAs) with international partners. Economic scenarios simulated in this step were shown in Table 4.1.

Table 4.1. Economics scenarios in water demand model.

case	Average growth rate	Internal effect	External effect or FTAs with partners	
			The global	U.S.A., JP, and CN
Case 1	O			
Case 2	O	O		
Case 3	O	O	O	
Case 4	O	O		O

Note: U.S.A. is the United States of America, JP is Japan, and CN is China.

First, economic growth rate of industrial, agricultural, and service sector was separately analyzed by using average growth of last 20 years from 1984 to 2004. The analyzed industrial growth rate in normal case was 8.2%.

Second, internal effect of economic scenario or Thai industrial cluster strategy was generated from the 9^{th} and 10^{th} national economic and social development plan of National Economic and Social Development Board (NESDB, 2005) and industrial master plan of Office of Industrial Economics (OIE, 2005). The main target of this policy was focused on industrial types of food, garment, electronic goods, and automobile.

Third, external effect of economic scenario or changing Thailand industrial market share was analyzed by focusing on the future plan of government agencies related to control industrial policy and possibility of movement of production base from the effect of declared policy and the world situations in free trade agreements or FTAs with international partner. Two main groups of partner were selected to simulate the external effect. The first one is FTAs with the global and the second is FTAs with the United States, Japan and China (OIE, 2005).

Water use units at base year were developed from the questionnaire survey of Kochi university of Technology (KUT, 2006), Chulalongkorn University (CU, 2005), and Industrial Water Technology Institute (IWTI, 2004). In the predicting step, decreasing water use unit were analyzed by using past pattern of decreased unit use of each ISIC code of Japan from 1968 to 1988. The reason of using this period is that the policy of groundwater use controlling in Japan was declared since 1968. Department of

Groundwater Resources of Thailand declared the same policy as Japan case since last 10 years that resulted in the difficulties to get more industrial water for industrial sector.

Finally, water demand in four economic scenario was calculated by using intermediate transaction in monetary term of million Thai baht (10^6 THB) from input-output table and decreasing water use unit in unit of million cubic meter per day per 10^6 THB ($Mm^3/d/10^6$ THB).

Water use unit analysis

Water use unit analysis is the main activities in the first step of water demand management model. Firstly, water demand in each province and industrial activity was calculated from intermediate transactions of input-output (IO) table model and water use unit analysis. Water use unit per monetary terms of product was calculated from the collection data from government agencies and questionnaire survey by Kochi University of Technology in 2006.

Firstly, number of questionnaire sample was designed by statistical analysis with 95 percentage significant level. 400 samples of each industrial and household questionnaire were needed to analyze. However, sending questionnaires were 2,000 samples in each sector because of 20 percentages of response rates. The number of sample in each province was weighted again with number and density of factories in 7 provinces. Figure 4.3 shows the scatter of questionnaire survey in industrial survey. Bangkok is the main target of this survey because of high density of industrial activities and population.

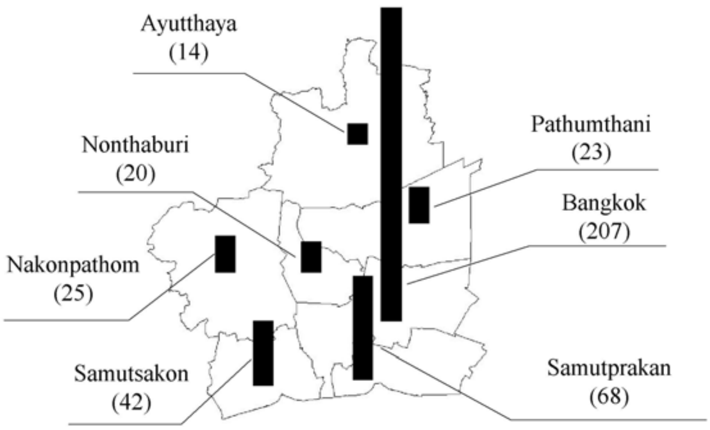


Figure 4.3. Scatter of industrial questionnaire samples.

Industrial questionnaire survey

There are 3 main topics in this survey. (The detail of industrial questionnaire is shown in appendix E). The first is water use and source. Monthly water use in average and maximum rate, water price, initial cost for investment, problem, and solution are collected in this topic. Water sources consist of tap water, groundwater, and surface water (pond, river, irrigation canal or natural canal).

The second topic is detail of water use in each source and activity such as production (raw material or washing), utility (boiler or cooling system), and office or dormitory. The special detail such as treated water before using will be collected in this topic.

The last part is concentrated in effect from pipe water, water saving policy in factory, trend of production capacity & use, water saving policy by government, and effect from pricing policy. The reason why effect from pipe water was concentrated is because of the problem of changing quality of production from using pipe water in textile, food and beverage factories which are the heavy water consumer in this area.

4.2.2 Water supply model

Water supply was analyzed from new water infrastructure plan from government agencies such as;

1. Tap water source from Metropolitan Waterworks Authority (MWA), and Provincial Waterworks Authority (PWA).
2. Groundwater source from Department of Groundwater Resources.
3. Surface water from Royal Irrigation Department (RID), and Department of Water Resources (DWR).

Laws and regulations such as groundwater ban laws were collected from these agencies to analyze water constraint or yield point. This permissible water will be the upper limit of water use that water users can get. From the problem of land subsidence in this study area, Department of Groundwater Resources declared GW use controlling policy to reduce GW use from maximum pumpage approximately 2.64 Mm^3/d in 1999 to meet permissible yield at 1.25 Mm^3/d for industrial sector (Buapeng, S., 2006). The reason that the full capacity of groundwater yield point was used in this model because now the ratio of water use in domestic is rapidly decreasing to 0 Mm^3/d from the data of Waterworks Authority by the groundwater ban law. The rapidly decreased GW supply by law was highly effected to industrial structure of Thailand and target economic output. In this chapter, there are two sources of water supply that support this decreased GW; tap water and recycled water. To reduce this problem, Metropolitan Waterworks Authority plan to construct new water supply system about 0.80 in total or 0.48 Mm^3/d for industrial sector (MWA, 2006).

4.2.3 Integrated water management model

In this topic, governmental option scenario was applied as integrated water management model analyzed by using outputs from water demand and supply models. Four scenarios of governmental options generated in this step were shown in Table 4.2.

Table 4.2. Governmental options scenarios in integrated water management model.

Governmental option scenarios	Subsidy by government agencies		New water infrastructure	
	With	without	With	Without
SUB-INF	O		O	
SUB-NOINF	O			O
NOSUB-INF		O	O	
NOSUB-NOINF		O		O

The cases of with and without new water infrastructure were generated by industrial water demand and supply curves to find the equilibrium point. The cases of subsidy cost from government agencies or paying higher cost by users (each factory) were analyzed by using benefit-cost analysis.

Finally, the impacts of each declared policy to the target of economic growth of Thailand can be calculated by using this water demand management model. Policy makers can choose the suitable strategy that use low invested cost with high budget that can keep the target of industrial growth or by each evaluation standard.

4.2.4 Strategic decision making

Strategic decision making model which is a part of industrial water demand management model was developed by using decision analysis approach to evaluate all expected possible benefits. Figure 4.4 shows decision tree with sequence of decision and chance nodes in 4 time periods or period_ws parameter. Each time period is 5 years. The small circle is chance node indicating an event of uncertain outcome. In this study, there are 3 chance; high, medium, and low demands. Occurrence possibilities in each chance were calculated by using Extended Pearson-Tukey method. By this method, the 5th, 50th, and 95th percentiles of water demand growth rates are assigned probability 0.185, 0.630, and 0.185. The sum of probabilities of all branches emanating from a chance node is one. Figure 4.5 shows cumulative distribution function for water demand growth rate from last 10 years.

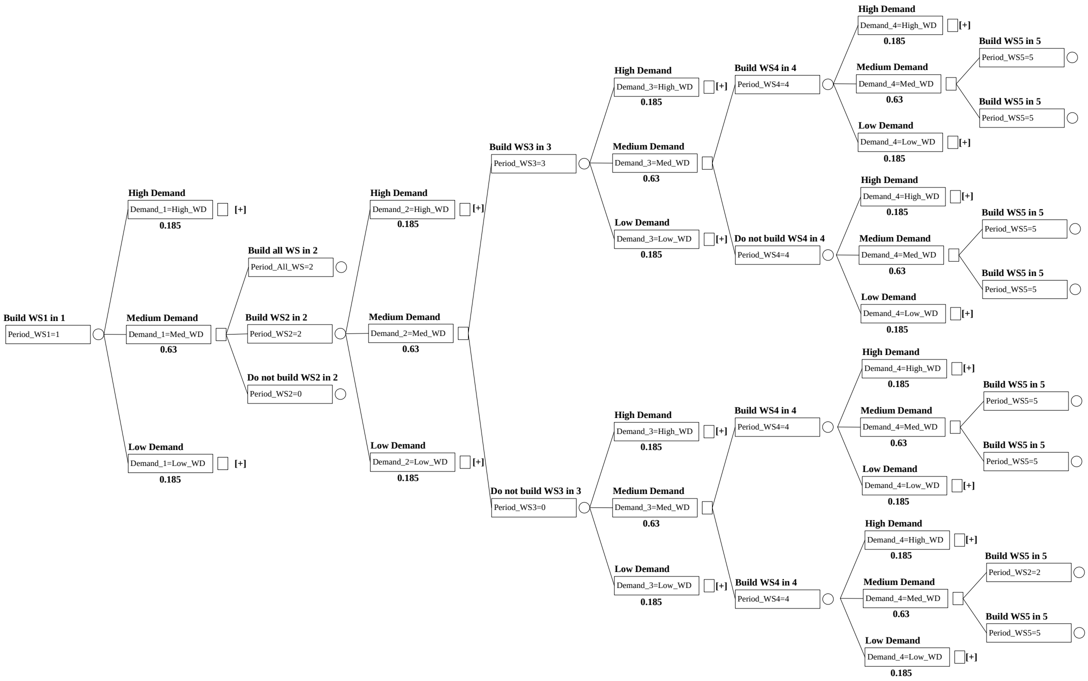


Figure 4.4. Decision tree structure with uncertainties of water demand.

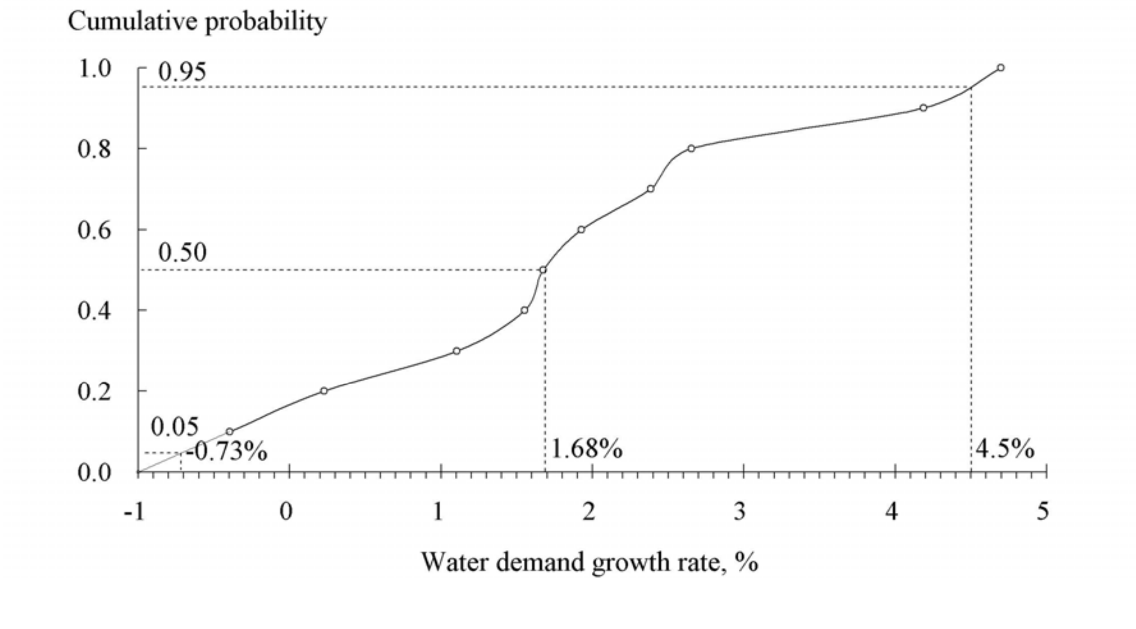


Figure 4.5. Cumulative distribution function for industrial water demand growth rate.

Decision node shown in Figure 4.4 indicates a point where the policy maker faces a decision. In this model, three decisions were presented; 1. To build all water infrastructure, 2. To build step by step, and 3. To do nothing. The last nodes or the ends of the paths denote the final outcome. Each outcome has the combined probability of all chance and it represents the possibility of that possible choice.

Expected benefits of each final path of decision tree were solved from right to left or backwards. Firstly, the values of final node were calculated by difference between benefit from using supported water and loss from excess water. However, the constraint of using water is save yield point of water supply in each source. The expected benefits of each period were the weighted average of the payoff in its branches by each branch's probability. Finally, net expected benefit of the project was the weighted average of the outcome of all paths by their possibilities.

4.2.5 Model formulation

From the previous topics, four models (water demand, water supply, integrated water management, and strategic decision making model) were developed as industrial water demand management model by using GAMs language.

This model was designed to run with the same order as schematic diagram shown in Figure 4.6 as follow;

1. Water demand model; Thailand and provincial Input-Output (IO) table model with economic scenarios, transformation IO data to ISIC code, water use unit analysis, and water demand model
2. Water supply model; demand-supply function and equilibrium analysis in each rate of recycled water
3. Integrated water management model; governmental option scenario
4. Strategic decision making model

This model was designed as toolbox for policy maker that can update scenarios in engineering, economic, environment, and society in the final process.

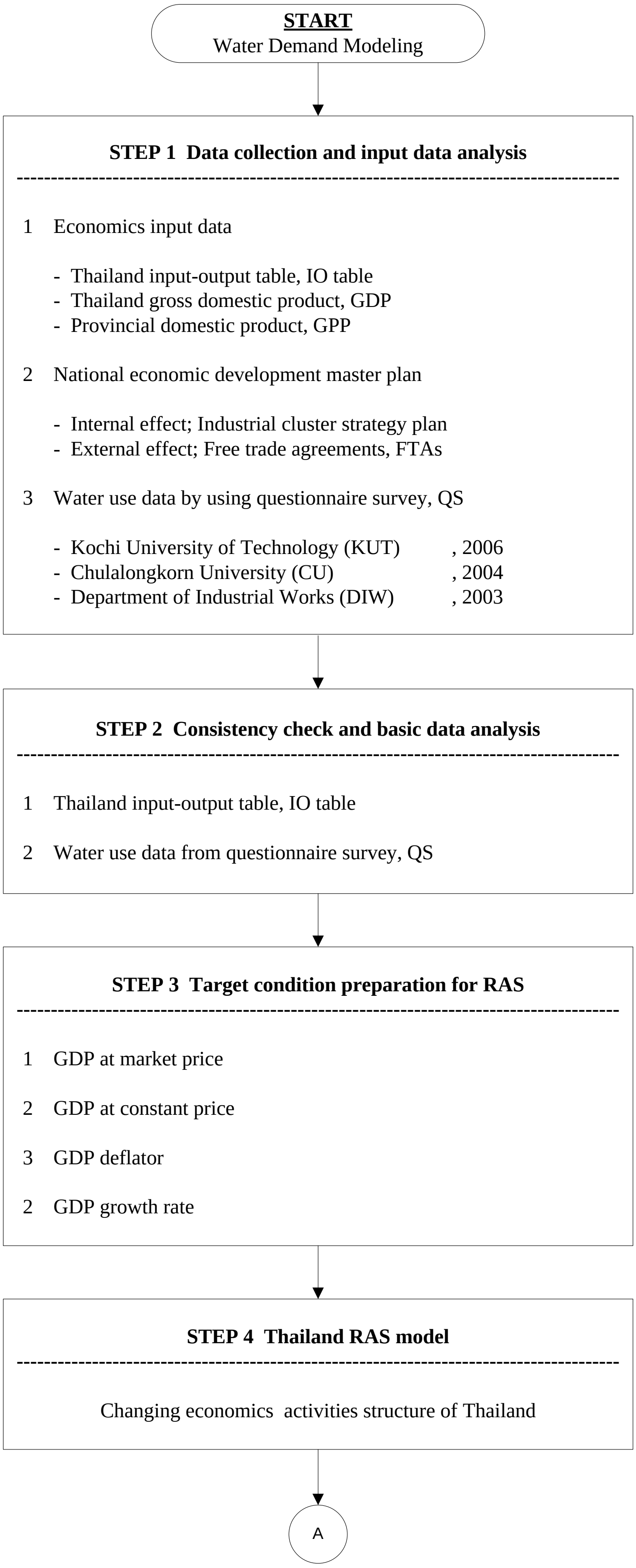


Figure 4.6. Schematic diagram of industrial water demand management model

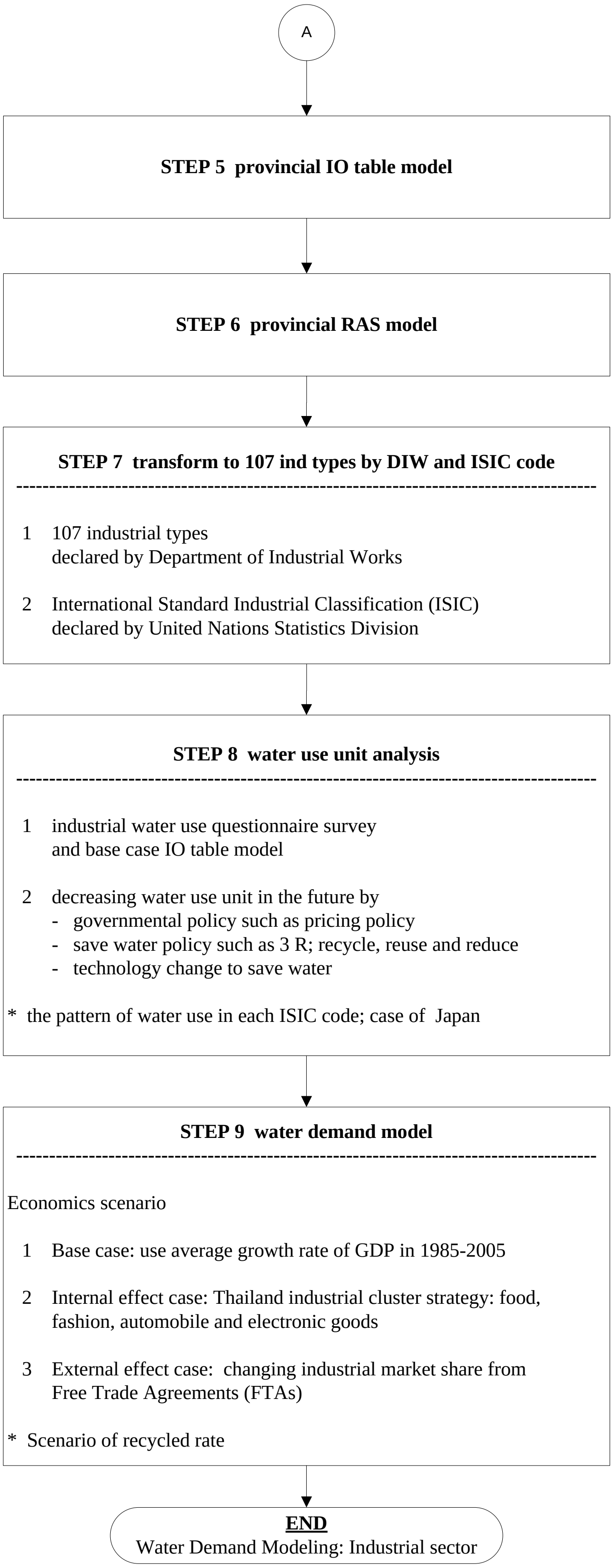


Figure 4.6. Schematic diagram of industrial water demand management model. (Cont’d)

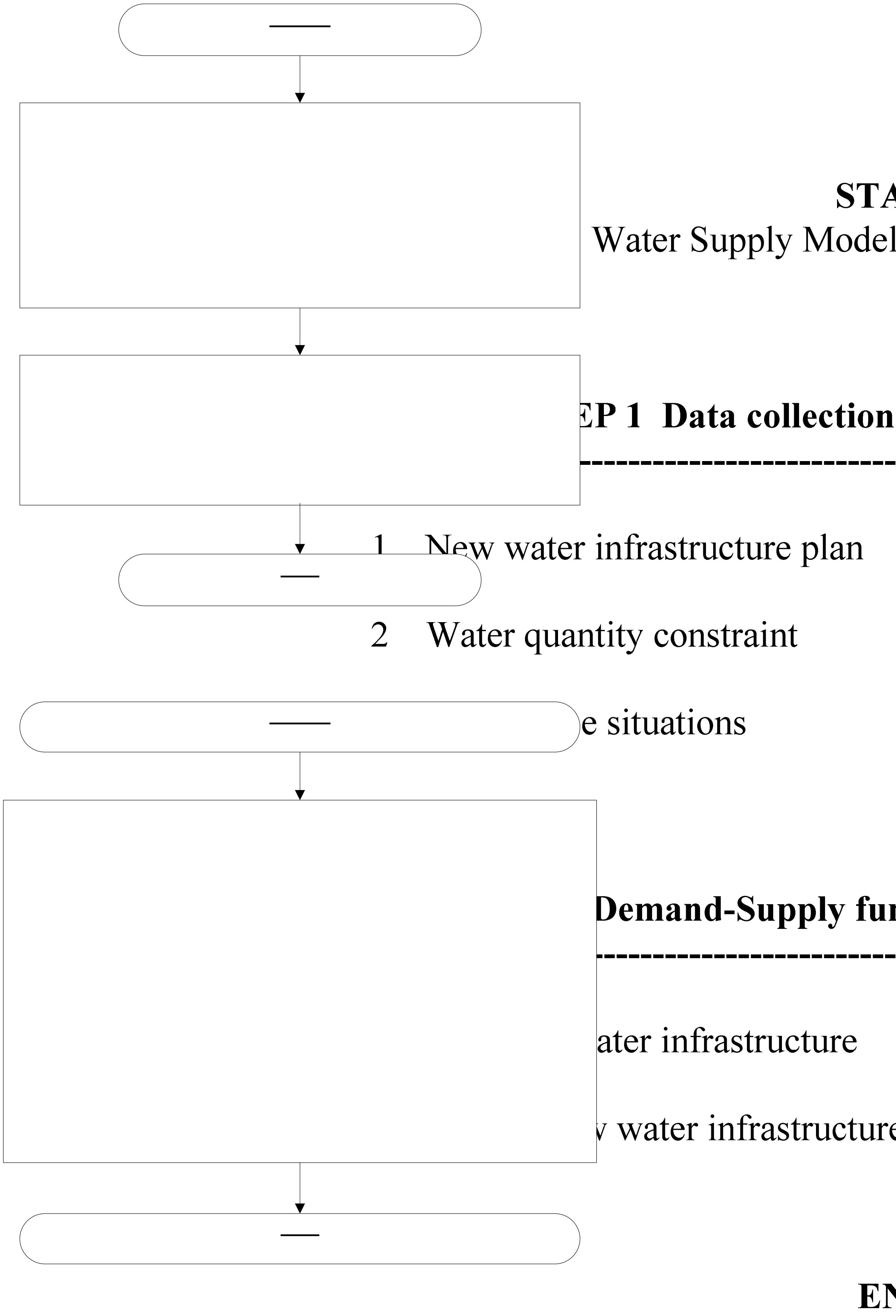


Figure 4.6. Schematic diagram of industrial water demand management model. (Cont'd)

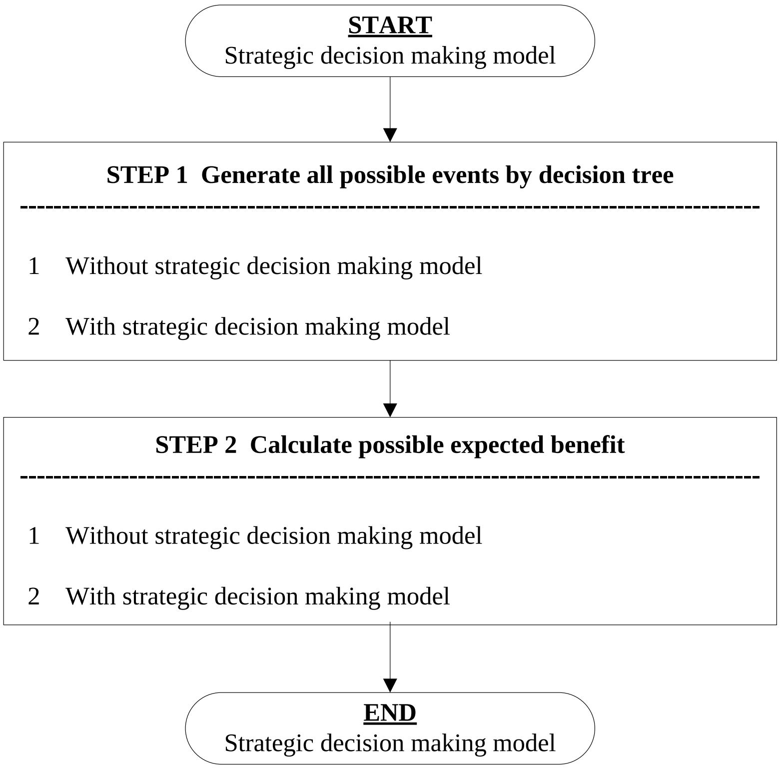


Figure 4.6. Schematic diagram of industrial water demand management model. (Cont'd)

4.3 Industrial Water Demand Management Model & Results

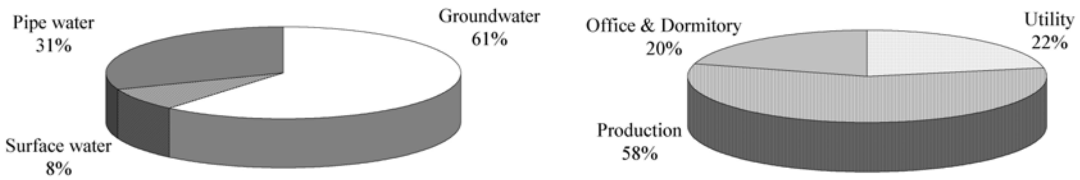
4.3.1 Water demand model

Water demand model started with Thailand and provincial input-output table shown in chapter 3. The next steps are water use unit analysis and the other steps as shown in last topic. This topic shows about the result of industrial water demand management model in details of economic, governmental option scenarios, and strategic decision making model.

Water use unit analysis

Figure 4.7 shows industrial water source and use by process. In study area, groundwater is main part with 61 percentages because main groundwater consumer such as textile, food, and beverage factories are located in this area especially Bangkok, Samut Prakarn, and Samut Sakhon.

This high percentage of groundwater use with limited groundwater quantity from declared regulation show conflict between groundwater demand and supply in this area. Production process is the highest water user with 57.6 percentages as shown in Figure 4.7. One of interesting constraint is limitation of recycled water percentage in production process because of the quality of water used in raw material and process in food and beverage factory type. (See details in Appendix G.)



(a) Water source (b) Water use by process

Figure 4.7. Industrial water source and use by process

(Source: Questionnaire survey.)

Figure 4.8 shows percentage of water use by source and objective of use in each province. Two main groups can be defined. The first one is the upper part of this study area with high percentage on surface water use. The reason is the good water quality of Chao Phraya River in this area. Factories can use surface water from main river and canal. The second one is the lower part of study area including Bangkok, Samut Sakhon, and Samut Prakan that mainly use groundwater because of good quality and cheap price.

Figure 4.9 shows the details of percentage of water use by source and objective of use in each ISIC code. This figure is strongly useful for policy makers to know the limitations of recycled water. In some industrial types such as food and beverage factories, recycled water cannot be used for production process including raw material. In Textile and leather industrial types, chlorine in pipe water will react in production process that changes the product quality. From these constraints, policy makers can assign the upper limit of recycled water or pipe water instead of groundwater. This limit has to be considered again whether is suitable with groundwater yield point.

Water demand in base year analyzed by Intermediate transactions from input-output table model and water use unit analysis from questionnaire survey by Kochi University of Technology is shown in Table 4.3. As can be seen in ISIC code D or Manufacturing, the industrial targets of government policy such as ISIC code 15, 17, 18, 19, 30, 31, and 34 can produce intermediate transaction approximately 1,282,738 million baht or 41.6 % of total in the study area and need water about 321 MCM in 2005 or 45.2 % of total water use. This high percentage means this industrial cluster is the main activity and water user.

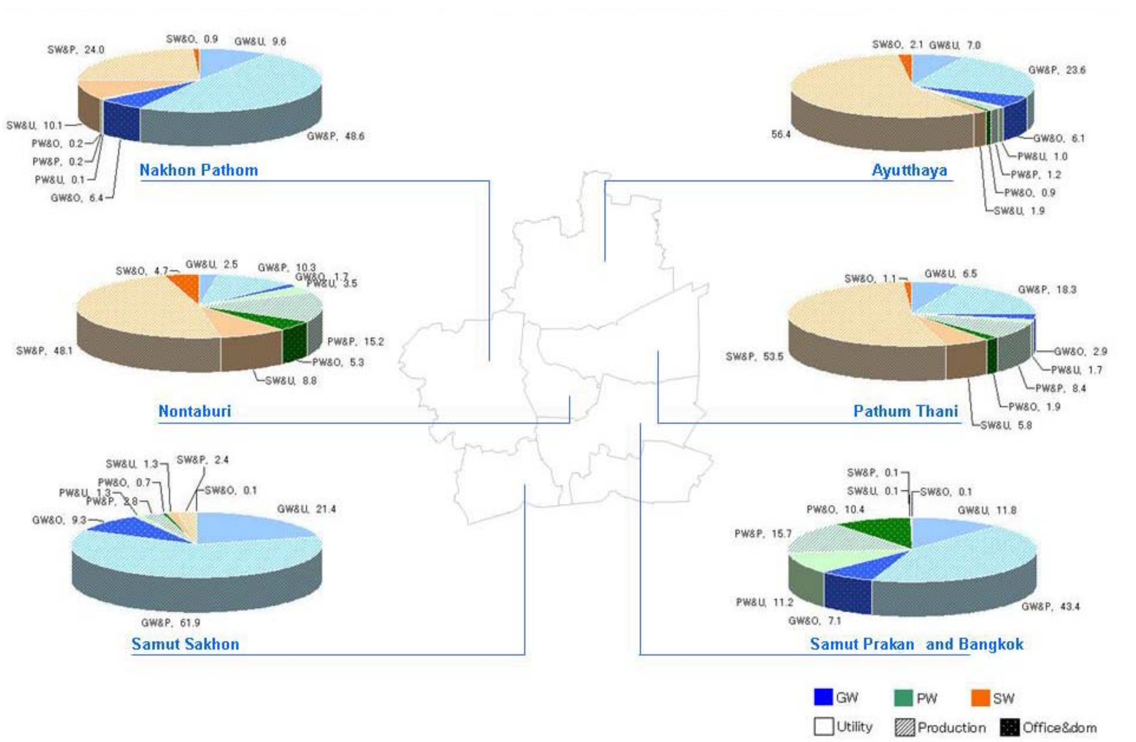


Figure 4.8. Percentage of water use by source and objective of use in each province

(Source: Questionnaire survey.)

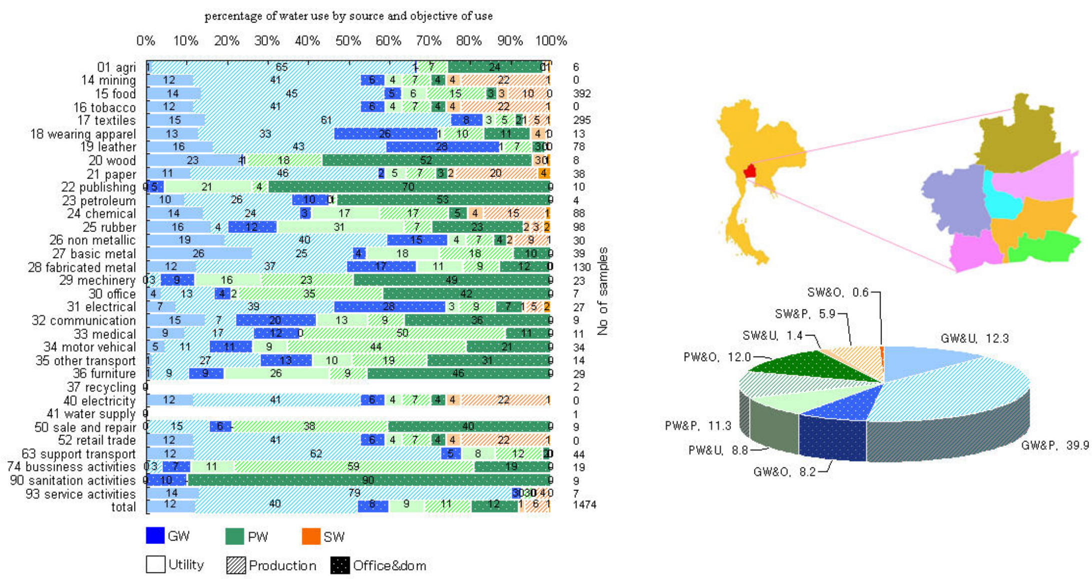


Figure 4.9. Percentage of water use by source and objective of use in each ISIC code.

(Source: Questionnaire survey.)

Table 4.3. Output and water demand classified by ISIC code, 2006.

ISIC code			Water unit	Intermediate transaction	Water demand	
Code*		Description	Cum/d/10^6	10^6 Baht	Cum/day	MCM/year
A	01	Agriculture and service	1.91	592	1,133	0.4
C	14	Other mining and quarrying	0.06	8,276	520	0.2
D	**15**	**Food products and beverages**	**0.37**	**532,112**	**194,495**	**71.0**
	16	Tobacco products	1.32	7,413	9,797	3.6
	17	**Textiles**	**0.90**	**233,454**	**209,050**	**76.3**
	18	**Wearing apparel**	**2.37**	**114,036**	**269,835**	**98.5**
	19	**Tanning and dressing of**	**1.95**	**65,660**	**128,051**	**46.7**
	20	Wood and of products of wood	0.26	19,519	5,049	1.8
	21	Paper and paper products	1.06	22,996	24,392	8.9
	22	Publishing, printing	0.37	24,393	9,018	3.3
	23	Coke, refined petroleum	0.01	242,666	1,446	0.5
	24	Chemicals and chemical	0.94	180,514	169,363	61.8
	25	Rubber and plastic products	0.42	119,743	50,495	18.4
	26	Other non-metallic mineral	0.17	67,778	11,496	4.2
	27	Basic metals	0.27	20,593	5,515	2.0
	28	Fabricated metal products	0.32	95,976	30,939	11.3
	29	Machinery	0.10	331,297	32,218	11.8
	30	**Office, computing machinery**	**1.73**	**22,579**	**39,088**	**14.3**
	31	**Electrical machinery**	**0.20**	**58,388**	**11,944**	**4.4**
	32	TV, and communication	0.10	312,995	30,755	11.2
	33	Medical and optical	0.33	38,703	12,709	4.6
	34	**Motor vehicles**	**0.13**	**134,919**	**17,461**	**6.4**
	35	Other transport equipment	0.09	121,591	10,386	3.8
	36	Furniture	1.67	151,784	252,869	92.3
	37	Recycling	0.00	1,827	0	0.0
E	40	Electricity, gas, steam supply	0.00	81,096	54	0.0
	41	Collection and distribution of	0.00	3,453	0	0.0
G	50	Sale and repair of motor	1.96	9,447	18,550	6.8
	52	Retail trade	0.08	35,385	2,797	1.0
I	63	Supporting transport activities	2.80	556	1,556	0.6
K	74	Other business activities	0.40	18,577	7,406	2.7
O	90	Sewage, sanitation activities	0.04	554	22	0.0
	93	Other service activities	53.13	7,378	391,955	143.1
		Study area	0.63	3,086,248	1,949,230	711.5

Note : * ISIC code : A = Agriculture, hunting and forestry, C= Mining and quarrying, D=Manufacturing, E=Electricity, gas and water supply, G=Wholesale and retail trade; repair of motor vehicles, I=Transport, storage and communications, K=Real estate, renting and business activities, O=Other community, social and personal service activities [2]. Remark: This calculated output and water demand classified by ISIC code were transformed from 107 industrial types of Department of Industrial Works.

Economic scenario: base case and internal effect scenario

Base case and internal effect scenario or economic scenarios 1 and 2 in Table 4.1 were analyzed in this topic. Figure 4.10 shows industrial water demand classified by ISIC codes and provinces. Bangkok, Samut Sakhon, and Samut Prakan are the main water user approximately 463 MCM in 2005 or 65 % of study area because of the huge economic activities in this area. Now the government declared this 7 provinces area as the critical groundwater zone to protect the land subsidence. This declared policy will result in the growth of industrial activities and water demand in the future.

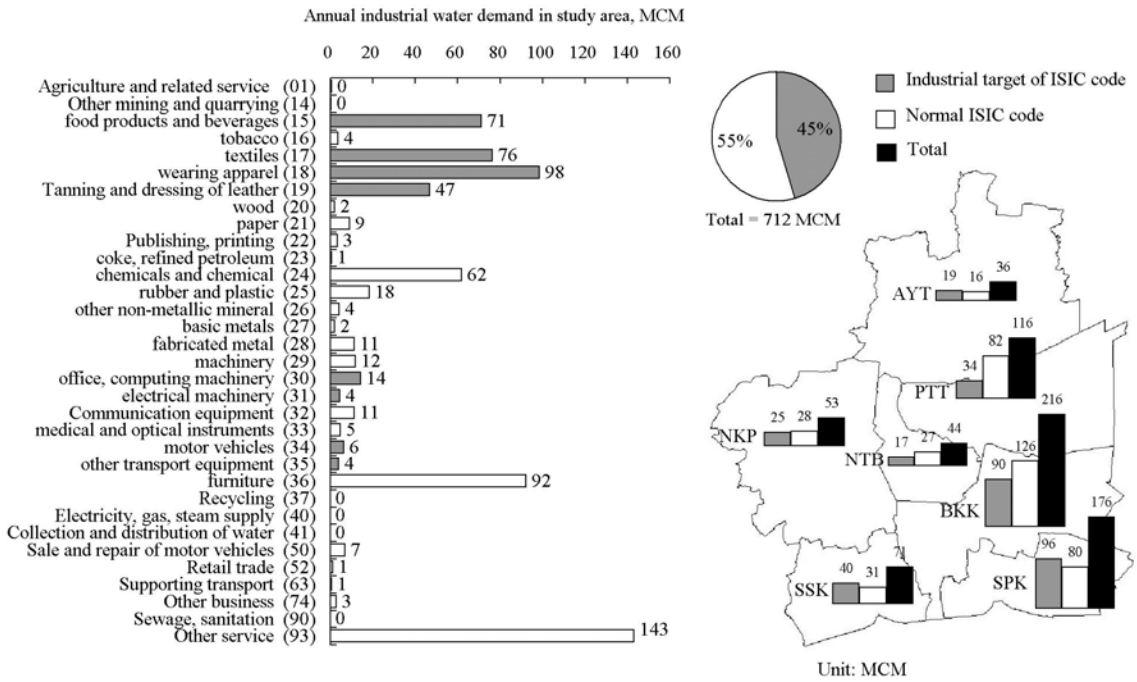


Figure 4.10. Industrial water demand in the Study Area, 2006: economic scenario 1.

Figure 4.11 shows the comparison between industrial water demand in case of normal growth and economic scenario of internal effect or Thai industrial cluster strategy. As can be seen, industrial water demand increases approximately 2.56 times from 2005 to 2025 because water demand grows to be dependent on growth of Thai gross domestic product (GDP). This increased water demand is quite high if compare with the historical data of Japan because the target GDP growth analyzed from the average value of last 20 years is constant rate about 6.2 % in total or 8.6 % in industrial sector.

For the case of applying Thailand industrial cluster strategy, the growth of water demand with the policy is more than the normal growth because food and textile clusters declared as Thai strategy need the high rate of water use unit per output. The difference of water demand between normal case and scenario of Thai strategy shows the quantity of water which policy makers should concern with the water supply side. If the water shortage occurs, one of the interesting solutions is demand side management to decrease the amount of water demand by using government policy, pricing policy, water saving technology, and other measures.

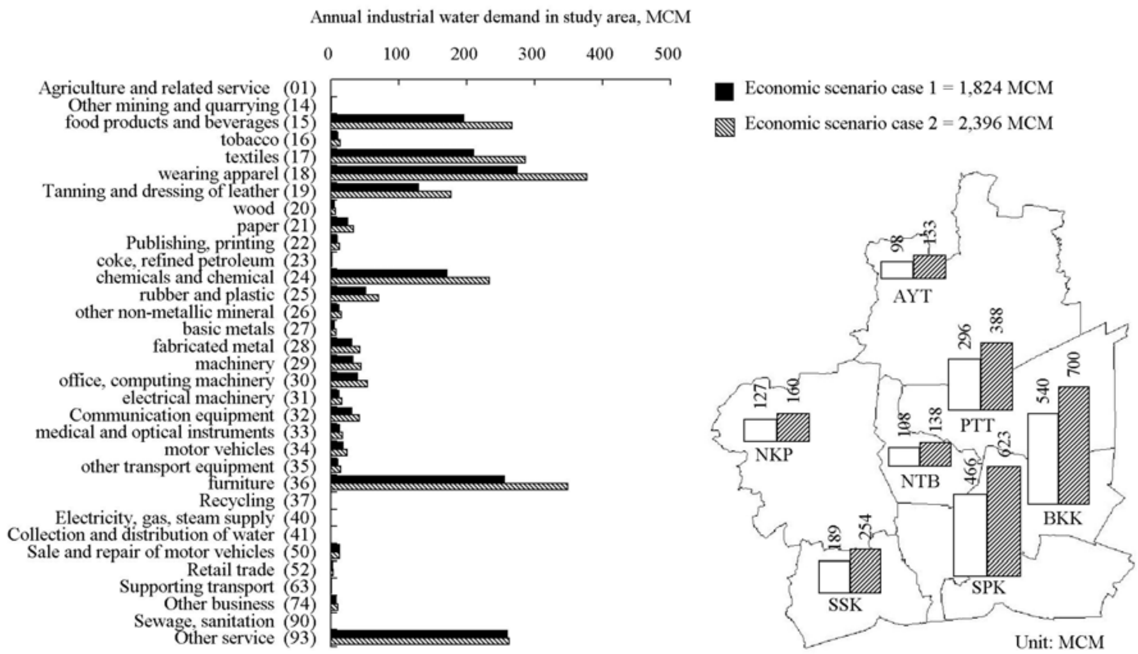


Figure 4.11. Industrial water demand in 2025: economic scenario 1, 2.

Economic scenario: External effect scenario

Table 4.4 shows changes of industrial output after using scenarios of economic external effect classified by ISIC code in 2025. The table shows how water demand change after applying FTAs with the global in case 3 and the group of the US, Japan and China in case 4.

As can be seen after applying FTAs, water user can be divided into 3 main groups as following. The first one needs more water such as food and fashion cluster. For the second group, water demand is less than the case without applying FTAs such as chemical, rubber, plastic and metal sectors. The last one is the group of constant water demand in case of with and without applying these agreements such as wood, paper, publishing, petroleum, office product, electronic product and service sector.

Table 4.4. Impacts of Free Trade Agreements on Industrial sectors (percent changes of output value, %)

code	ISIC	scenarios of economic external effect	
		FTAs with global	FTAs with U.S.A., Japan, and China
15	Food products	12.28	22.77
16	Tobacco products	-3.64	2.70
17	Textiles	1.70	5.11
18	Wearing apparel	9.10	12.52
19	Leather products	8.40	14.70
20	Wood products	-8.33	-4.72
21	Paper products	-2.40	0.81
22	Publishing	-2.40	0.81
23	Petroleum, coal products	1.62	0.85
24	Chemicals products	-4.74	-1.84
25	Rubber and plastic products	-4.74	-1.84
26	Non-metallic products	-1.92	0.09
27	Basic metals	-0.0	-4.65
	Metal product	-7.09	-5.96
28	Fabricated metal products	-8.45	-6.60
29	Machinery	4.26	0.08
30	Office machinery	-1.92	0.09
31	Electrical machinery	3.44	-0.07
32	Communication equipment	3.44	0.07
33	Medical instruments	-1.92	0.09
34	Motor vehicles	-20.44	-16.16
35	Other transport equipment	50.98	-1.92
36	Furniture	-1.92	0.09
37	Recycling	na	na

Source: edited from Office of Industrial Economics

According to the results shown in table 4.5, figure 4.12 and 4.13, industrial sectors need more water after applying FTAs in global scale as showed in case 3 and bilateralism agreement with the US, Japan and China in case4.

Table 4.5. Industrial water demand in each cases classified by ISIC code, 2025

ISIC code			Water demand in each cases, MCM/year			
Code		Description	Case 1 normal	Case 2 normal industrial	Case 3 Case 2 and with global	Case 4 Case 2 and with US, JP,
A	01	Agriculture and service	0.4	0.4	0.4	0.4
C	14	Other mining and quarrying	0.5	0.7	0.7	0.7
D	15	Food products and	195.5	266.8	291.1	316.7
	16	Tobacco products	10.1	13.9	13.4	14.3
	17	Textiles	210.0	286.6	291.5	301.2
	18	Wearing apparel	274.4	377.0	411.3	424.2
	19	Tanning and dressing of	129.2	176.6	191.4	202.5
	20	Wood and of products of	5.1	7.0	6.4	6.6
	21	Paper and paper products	24.6	33.7	32.8	33.9
	22	Publishing, printing	9.2	12.6	12.3	12.7
	23	Coke, refined petroleum	1.5	2.0	2.0	2.0
	24	Chemicals and chemical	170.7	233.1	222.1	228.9
	25	Rubber and plastic products	51.0	69.7	66.4	68.4
	26	Other non-metallic mineral	11.6	15.8	15.5	15.8
	27	Basic metals	5.5	7.5	7.5	7.2
	28	Fabricated metal products	31.2	42.6	39.0	39.8
	29	Machinery	32.4	44.2	46.1	44.3
	30	Office, computing	39.4	53.8	52.7	53.8
	31	Electrical machinery	12.0	16.4	17.0	16.4
	32	TV, and communication	30.9	42.2	43.7	42.2
	33	Medical and optical	12.8	17.5	17.1	17.5
	34	Motor vehicles	17.6	24.0	19.1	20.1
	35	Other transport equipment	10.5	14.3	21.6	14.0
	36	Furniture	255.1	348.9	342.2	349.2
	37	Recycling	0.0	0.0	0.0	0.0
E	40	Electricity, gas, steam	0.0	0.0	0.0	0.0
	41	Collection and distribution	0.0	0.0	0.0	0.0
G	50	Sale and repair of motor	12.4	12.6	12.6	12.6
	52	Retail trade	2.5	3.3	3.3	3.3
I	63	Supporting transport	1.0	1.0	1.0	1.0
K	74	Other business activities	7.5	10.3	10.3	10.3
O	90	Sewage, sanitation activities	0.0	0.0	0.0	0.0
	93	Other service activities	259.8	262.8	262.8	262.8
Study area			1,824.0	2,396.9	2,453.0	2,522.6

Note: * US: the United States of America, JP: Japan, CN: China

Base on the results of case 4 which is recommended by Office of Industrial Economics (OIE) as shown in Figure 4.12, the higher production was supported by FTAs mainly in food and fashion sectors which have the main production base in the study area. From this reason, water demand in case 4 is more than case 2 approximatly 126 MCM in 2005. This higher demand will become critical in this area because of the limitation of water supply from the groundwater pumpage closing to protect the land subsidence and the high quality for production process in food and fashion sectors. In some factories, production line cannot use the pipe water because of the changed quality of products by chlorine.

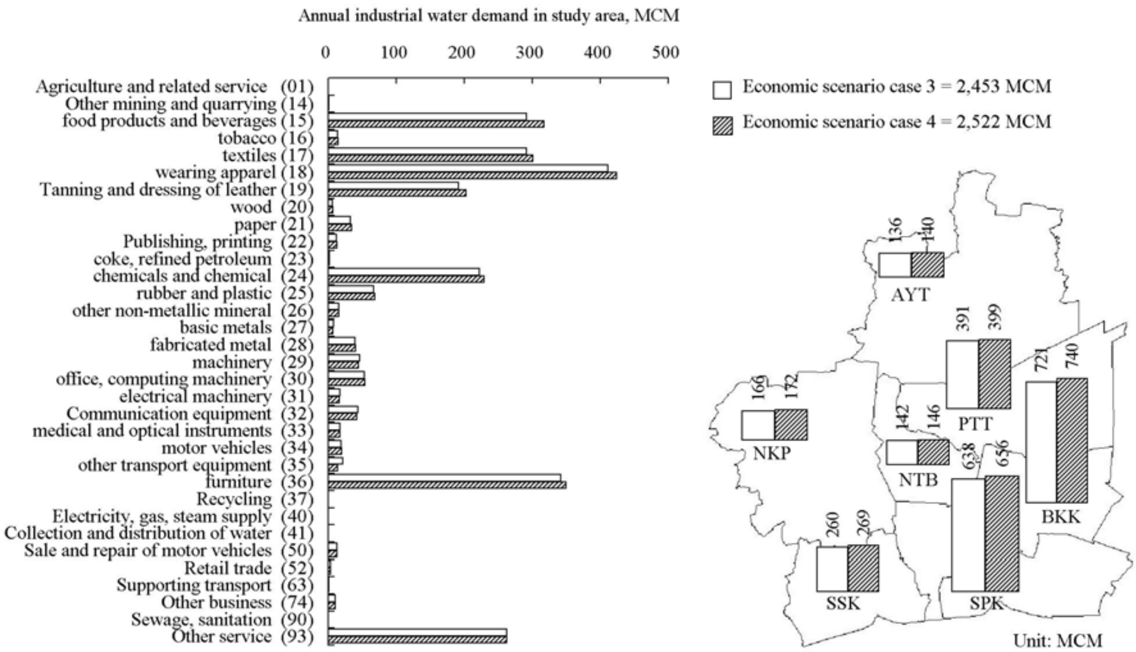


Figure 4.12. Industrial water demand in 2025: economic scenario 3, 4.

Industrial water demand classified by ISIC code and water demand in each province compared between case 2 and 4 in 2025 was shown in Figure 4.13. Textile, food and chemical products are the top three main water users in this area approximately 53 % of total water use. After applying FTAs, textile and food sector need more water but the water use in chemical sector decrease. The main reason is the higher and lower production needed from partners in FTAs.

Samut Prakan, Bangkok and Samut Sakhon are the top three main water users in study area about 66 % of total because of the high density of factories. After applying FTAs, these three provinces need more water and most of fashion factories located in this area needs the high quality water such as groundwater may have problem form this policy.

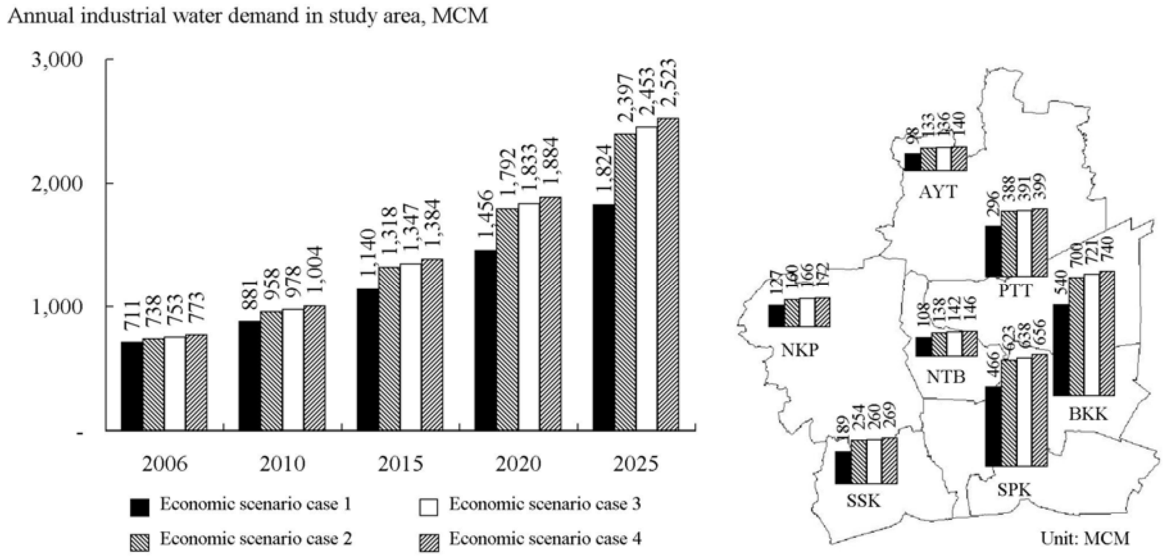


Figure 4.13. Industrial water demand in each economic scenario from 2005 to 2025.

The industrial water demand increase rapidly in this period since industry is the main part concentrated by Thai government declared in the 9th and 10th national economic and social development plan, Thai industrial master plan and international trade by FTAs. However, Thai government has to concern about the higher water demand affected from declared policy and provide water supply or water demand measure to decrease the water use in this area.

Recycled water's rate scenario: percentage of possible maximum rate in each ISIC code

Rate of recycled water used in model was analyzed by using collected data of recycled water of Japan case in period of 1958 to 2001. Now the recycled rate of Japan is constant as shown in table 4.6 and Appendix G. The important assumption in this scenario is that recycled rate of water in Japan is the possible maximum rate in Thailand. In this model, recycled rate of water was defined as 3 scenario; 0, 50, and 100 % of each ISIC code in case of Japan.

The objective of this scenario of rate of recycled water is to forecast water demand needed in each recycled rate. Now the recycled water is more expensive than other sources. Form this reason; the recycled water is one of interesting measure that should be considered under pricing policy. By the demand-supply law, if the price of this water is high, users would like to use the lower price with acceptable quality and quantity. However, if users face water shortage problem, they have to change to use recycled water that can be managed without new water source.

Table 4.6. Rate of recycled water in case of Japan, 1958-2001.

ISIC code			Rate of recycled water %	
Code		Description	Maximum value in the first 20 years	Maximum value 1958-2001
D	15	Food products and beverages	26.3	38.8
	17	Textiles	19.2	23.0
	18	Wearing apparel	0.3	10.7
	19	Tanning and dressing of leather	4.5	6.7
	20	Wood and of products of wood	6.6	13.9
	21	Paper and paper products	37.4	45.1
	22	Publishing, printing	34.9	59.4
	23	Coke, refined petroleum products	84.2	90.6
	24	Chemicals and chemical products	34.9	59.4
	25	Rubber and plastic products	58.5	64.5
	26	Other non-metallic mineral products	61.1	74.4
	27	Basic metals	87.7	90.6
	28	Fabricated metal products	23.6	50.6
	29	Machinery	53.4	66.9
	31	Electrical machinery	54.4	71.3
	33	Medical and optical instruments	16.6	24.5
	34	Motor vehicles	86.2	92.2
	36	Furniture	2.6	75.4
		Study area	46.9	78.1

Source: http://www.stat.go.jp, http://www.meti.go.jp

The following questions are following; 1. How much do the effects result to changing industrial structure because of higher cost? 2. Does Thai government subsidize for this higher cost to keep the economic target or push this cost to users? 3. How much do the impacts to the economic target comparing between higher costs from investment and benefits from more water?

Figure 4.14 and 4.15 show the results of rates of recycled water; 0, 50, and 100 % of case of Japan. The figures show that 100 % of recycled rate can save water approximately 573 million cubic meter per year in 2005 or 23 % in total. This percentage is low if compared with Japan case because the factories located in study area mainly food, beverage and garment group cannot use high rate of recycled water. The reason is that these industrial types need water in process of production as raw material and washing material consumed high quality of water. In case of Japan, groups of high rates of recycled water are group of metal, petroleum, and motor with more than

90 % recycled rate. This high recycled rate was use in utility process such as cooling system or boiler.

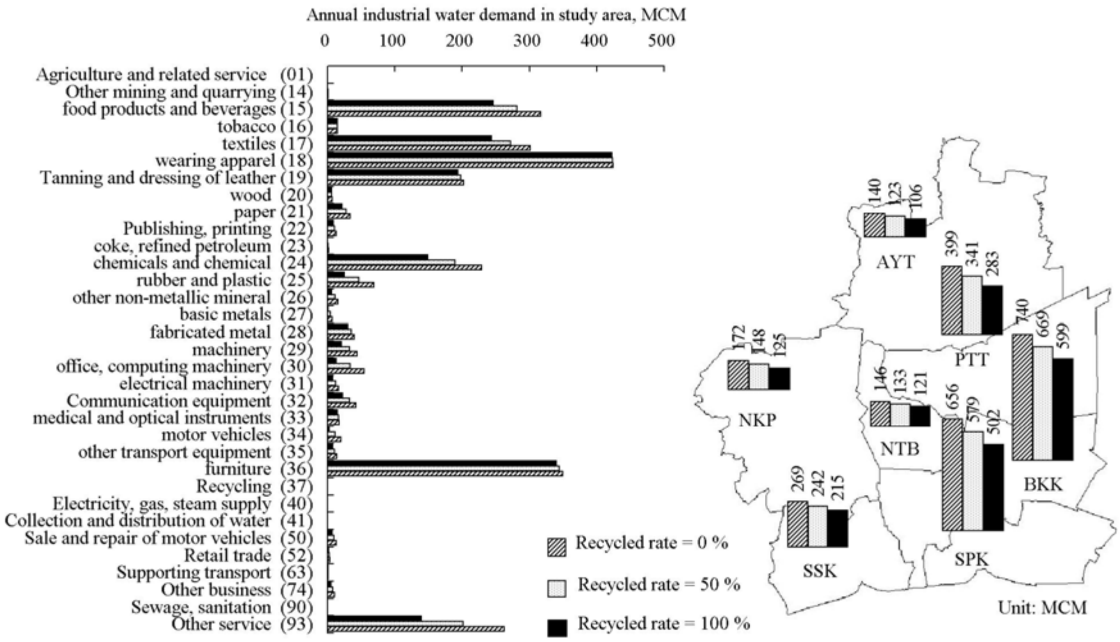


Figure 4.14. Industrial water demand by scenario of rate of recycled water in each ISIC code.

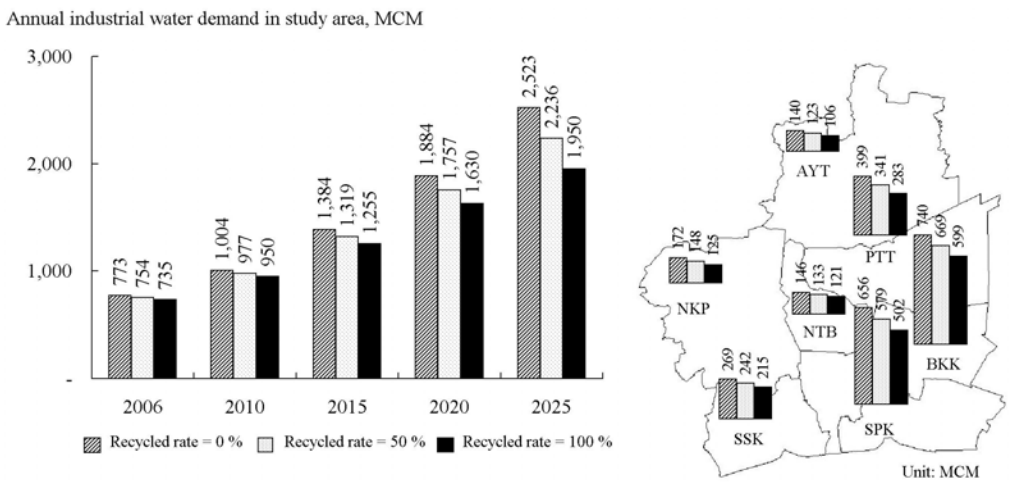


Figure 4.15. Industrial water demand by scenario of rate of recycled water from 2005 to 2025.

It is certain that recycled water is one of interesting measure to manage water demand and supply in this area, however, policy makers have to concern about the constraints of recycled rate in each ISIC code also. Unfortunately, the main industrial sector in this area can consume recycled water in low rate because of the process of production. The next topic will show the impact from recycled rate to economic target.

4.3.2 Water supply model and integrated industrial water management model

This topic shows about integrated industrial water management model with governmental option scenarios by using water demand-supply curve and benefit-cost analysis to find the maximum benefit in both government and factory side. Four scenarios with two main topics (with/without new water infrastructure and who pay the higher water cost) were applied in this step as shown in Table 4.2.

Figure 4.16, 4.17, and 4.18 shows how industrial water demand and supply curve can simulate with four governmental options' scenarios with 100, 50, and 0 % rate of recycled water by order. The groundwater (GW) demand for selected economic scenario is shown in demand curve named D. Demand curve named D line was analyzed from the real data of groundwater use from Department of Groundwater Resources. D' and D'' line are demand curves by the declared strategy to define possible industrial water use with willingness to pay at each level of water use.

Water supply curve named S1 was analyzed based on possible water supplied from each water source. The sources consist of maximum groundwater yield point (1.25 $M.m^3/d.$), pipe water of new master plan to support only industrial sector (1.25 $M.m^3/d.$), and recycled water (depended on recycled rate). S2 curve was defined as same as S1 without pipe water or new infrastructure from governmental side.

The point EP1 and EP 2 were defined as equilibrium point of demand and supply curve in each scenario. EP1 or equilibrium point at base year means the factory can use groundwater at 1.23 $M.m^3/d.$ with willingness to pay of 15.33 THB/m^3. The equilibrium point can move depending on shifting of demand and supply curve. There are many reasons that the demand and supply curve shift to upper and lower positions such as; changing water use pattern, changing water supply support, and etc.

In case of with new water infrastructure (INF), supply curve named S1 was illustrated in form of step function with three water sources. The water supply and price were shown in each source (GW, 1.25 Mm^3/d, 15.33 THB/m^3; tap water (TW), 0.48 Mm^3/d, 16.92 THB/m^3; recycled water (RW), 20.00 THB/m^3). From the demand and supply curve in this case, the equilibrium point, EP1, was 1.23 Mm^3/d at price 15.33 THB/m^3. If the results were compared among each recycled rate, it was seem that only case of 100 % of maximum possible recycled water has no water shortage. By this rate, there is water surplus approximately 0.32 M.m^3/d. or enough water to support declared governmental policy (2.96 M.m^3/d.). In case of 50 and 0 % rate of recycled water, there is water shortage in both cases.

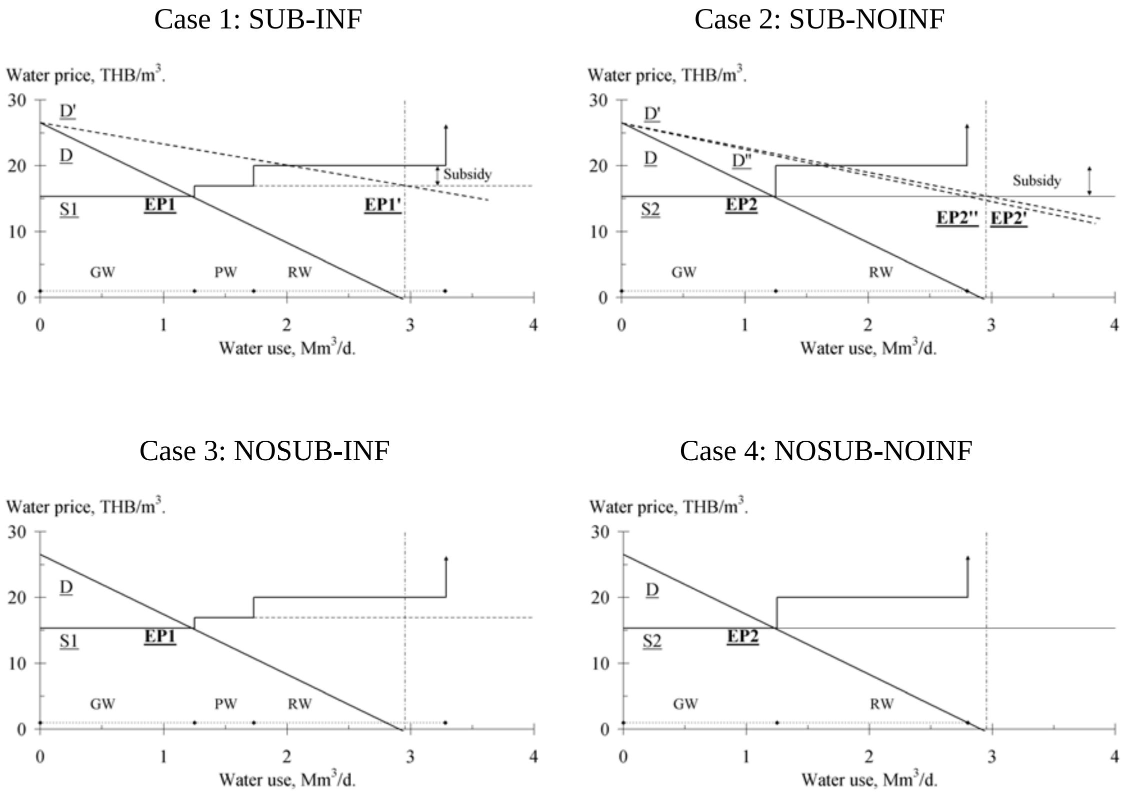


Figure 4.16. Industrial demand and supply curve in each governmental option scenario with 100 % rate of recycled water.

In case of without new water infrastructure (NOINF) there is only two steps function for supply curve named S2. The first level or GW supply is as same as the previous case but the second step is recycled water (RW) at 20.00 THB/m^3. The equilibrium point, EP2, in this case was 1.23 Mm^3/d at 15.33 THB/m^3. By scenarios of recycled water, all case face water shortage problem. It means that only groundwater and recycled water cannot support water demand from master plan or industrial development cannot reach the target of governmental side with this water condition.

In case of with and without subsidy, the main different point is the shift of demand curve. The shifted demand curve can move the equilibrium point to the point of more water use. This subsidy policy is the main measure to reach the target of master plan.

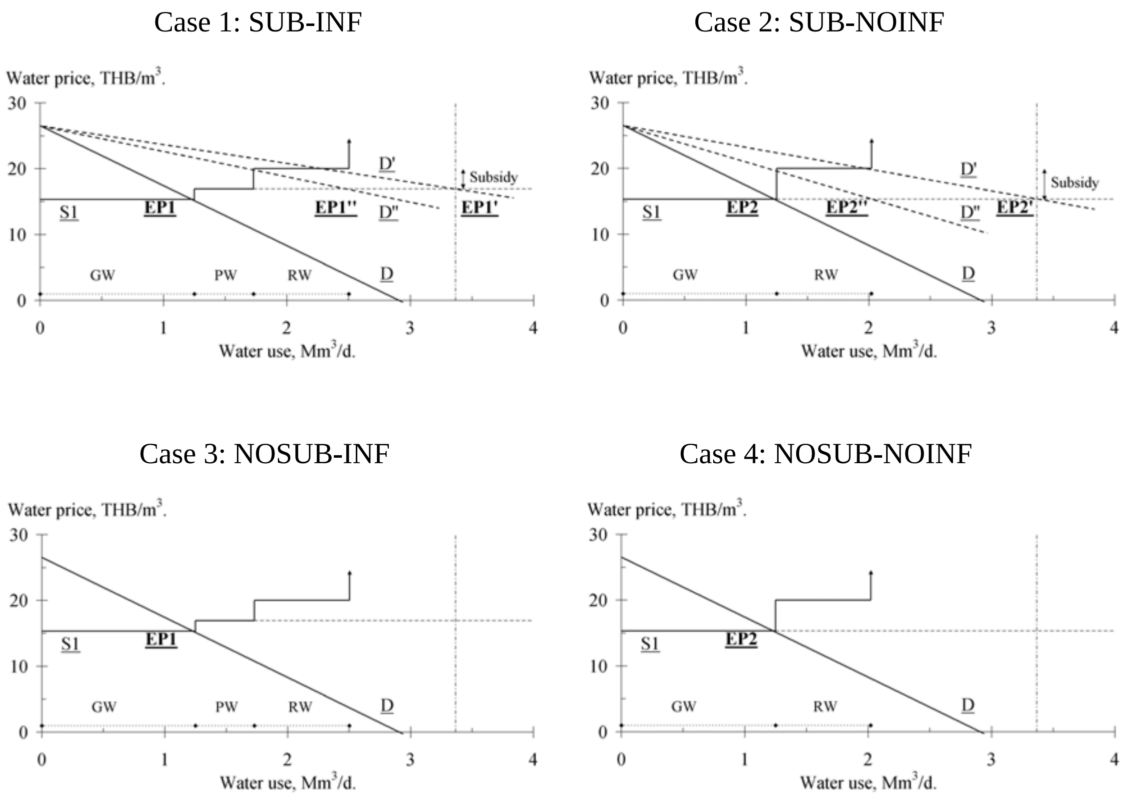


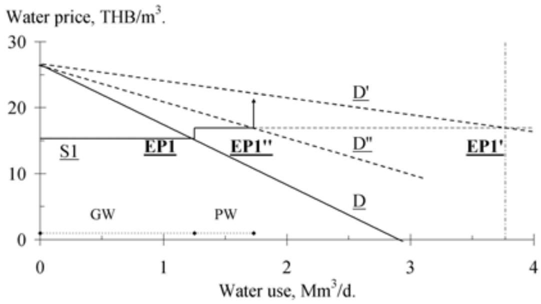
Figure 4.17. Industrial demand and supply curve in each governmental option scenario with 50 % rate of recycled water.

Figure 4.16 to 4.18 show the effect from rate of recycle to industrial water demand supply curve. If compared with figure 4.16, the higher rate of recycled water is, the lower industrial water is needed. The percentage of recycled water in figure 4.16 to 4.18 is not high if compared with Japan case because the main industrial sector in this area can consume recycled water in low rate because of the process of production. Case of 0 % of recycled rate of Japan case means there is no infrastructure to produce recycled water. Form this reason, the result of case 1 is as same as case 3 and case 2 is as same as case 4 shown in figure 4.18.

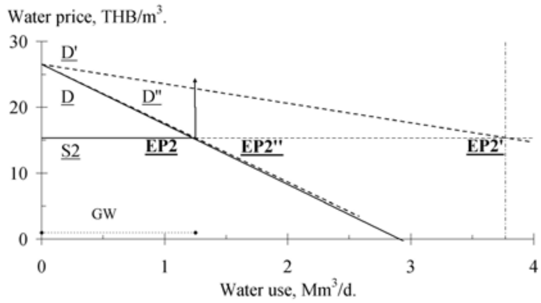
Table 4.7 shows the results of water demand management model in case of governmental options' scenarios with 0 % rate of recycled water. Total costs were analyzed from two topics. The first is subsidy cost and the second is artificial groundwater (GW) recharge to keep the GW yield. The benefit was calculated from added economic benefits that consume more GW from needed GW at equilibrium point.

As can be seem in Table 4.7, 0 % rate of recycled water means there is no infrastructure to produce recycled water. Form this reason, the result of case 1 is as same as case 3 and case 2 is as same as case 4.

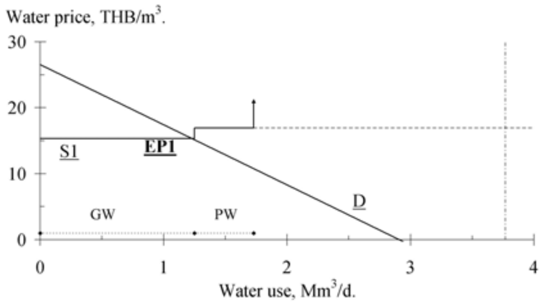
Case 1: SUB-INF



Case 2: SUB-NOINF



Case 3: NOSUB-INF



Case 4: NOSUB-NOINF

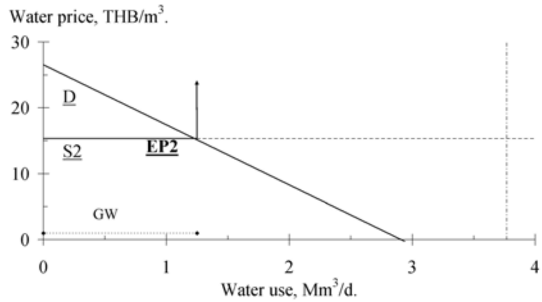


Figure 4.18. Industrial demand and supply curve in each governmental option scenario with 0 % rate of recycled water.

Table 4.8 and 4.9 show results of cost-benefits analysis, impacts from governmental options' scenarios and pricing policy with 50 and 100 % rate of recycled water. If compared these two cases with the case of 0 % recycled rate, case of 100 % rate can get maximum benefit because industrial sector can use more water for production. However, the economic growth rate is still less than the target because of investment cost in new infrastructure. It means that only possible maximum recycled water is not possible to get the governmental target. Policy makers should consider whether policy is suitable with constraints of water in this area. They have many measures to control such as; (1) to reduce the governmental target, (2) to construct more water infrastructure to support higher demand, and etc.

Evaluation standard

For policy makers, there is a question how to select the suitable governmental options to declare and use.

Table 4.7. Cost-benefits analysis, impacts from governmental options' scenarios and pricing policy with 0 % rate of recycled water.

	Unit	Case 1 SUB-INF	Case 2 SUB-NOINF	Case 3 NOSUB-INF	Case 4 NOSUB-NOINF
Equilibrium point					
GW use	Mm^3/d	1.231	1.231	1.231	1.231
Price	THB/m^3	15.33	15.33	15.33	15.33
Demand by policy					
GW	Mm^3/d	3.777	3.777	1.231	1.231
Total	Mm^3/d	6.912	6.912	4.366	4.366
GW with pricing policy					
GW demand	Mm^3/d	3.777	3.777	1.231	1.231
GW demand's price	THB/m^3	16.92	15.33	15.33	15.33
GW supply's price	THB/m^3	20	20	20	20
GW subsidy	THB/m^3	3.08	4.67	0	0
Cost-benefits analysis					
Subsidy cost	10^6 THB/d	0.000	0.000	0.000	0.000
Added economic benefit	10^6 THB/d	8,098	87	0.000	0.000
Total impacts	10^6 THB/d	8,098	87	0.000	0.000
Industrial growth rate					
Target	**%**	**9.7**	**9.7**	**9.7**	**9.7**
With pricing policy	**%**	**0.055**	**0.003**	**0.003**	**0.003**
Impacts	**%**	**-9.645**	**-9.697**	**-9.697**	**-9.697**
Recycled water	**Mm^3/d**	**0**	**0**	**-**	**-**
Water shortage	**Mm^3/d**	**2.047**	**2.527**	**-**	**-**

There are many ways to choose the suitable option with constraints in this area. Evaluation standards are the tools for government to make a decision. In this industrial sector, there are 3 evaluation standards used in this study as follow;

1. To maximize net benefit:

This standard is concentrated to choose the governmental option that produce maximum net benefit or maximum of (benefit – cost). Table 4.7, 4.8, and 4.9 show that maximum net benefit from using groundwater is case 1. It means that policy maker should construct the new infrastructure to support higher industrial water demand and subsidize the higher price form new equilibrium point to support water from declared governmental target. The factory side have benefited from the policy of subsidy cost. In the view point of policy makers, it seems that the case 1 is the suitable option that factory and government side get the maximum benefit.

2. To maximize GDP growth rate or to minimize impacts to target of GDP growth rate from governmental option and pricing policy.

The target of industrial GDP growth rate is 9.7 % including internal effect, industrial master plan, and external effect, free trade agreements or FTA. The water use and industrial activities structure in this area will change because changing condition of water supply and price by declared government options. The suitable option form this evaluation standard is case 1 that produce maximum GDP growth rate in all case of recycled rate.

Table 4.8. Cost-benefits analysis, impacts from governmental options' scenarios and pricing policy with 50 % rate of recycled water.

	Unit	Case 1 SUB-INF	Case 2 SUB-NOINF	Case 3 NOSUB-INF	Case 4 NOSUB-NOINF
Equilibrium point					
GW use	Mm^3/d	1.231	1.231	1.231	1.231
Price	THB/m^3	15.33	15.33	15.33	15.33
Demand by policy					
GW	Mm^3/d	3.366	3.366	1.231	1.231
Total	Mm^3/d	6.128	6.128	3.993	3.993
GW with pricing policy					
GW demand	Mm^3/d	3.366	3.366	1.231	1.231
GW demand's price	THB/m^3	16.92	15.33	15.33	15.33
GW supply's price	THB/m^3	20	20	20	20
GW subsidy	THB/m^3	3.08	4.67	0	0
Cost-benefits analysis					
Subsidy cost	10^6 THB/d	-6.576	-9.971	0.000	0.000
Added economic benefit	10^6 THB/d	91,022	24,374	0.000	0.000
Total impacts	10^6 THB/d	91,007	24,364	0.000	0.000
Industrial growth rate					
Target	**%**	**9.7**	**9.7**	**9.7**	**9.7**
With pricing policy	**%**	**2.418**	**0.589**	**0.003**	**0.003**
Impacts	**%**	**-7.282**	**-9.111**	**-9.697**	**-9.697**
Recycled water	**Mm^3/d**	**0.772**	**0.772**	**-**	**-**
Water shortage	**Mm^3/d**	**0.864**	**1.344**	**-**	**-**

Table 4.9. Cost-benefits analysis, impacts from governmental options' scenarios and pricing policy with 100 % rate of recycled water.

	Unit	Case 1 SUB-INF	Case 2 SUB-NOINF	Case 3 NOSUB-INF	Case 4 NOSUB-NOINF
Equilibrium point					
GW use	Mm^3/d	1.231	1.231	1.231	1.231
Price	THB/m^3	15.33	15.33	15.33	15.33
Demand by policy					
GW	Mm^3/d	2.955	2.955	1.231	1.231
Total	Mm^3/d	5.344	5.344	3.619	3.619
GW with pricing policy					
GW demand	Mm^3/d	2.955	2.955	1.231	1.231
GW demand's price	THB/m^3	16.92	15.33	15.33	15.33
GW supply's price	THB/m^3	20	20	20	20
GW subsidy	THB/m^3	3.08	4.67	0	0
Cost-benefits analysis					
Subsidy cost	10^6 THB/d	-5.311	-8.053	0.000	0.000
Added economic benefit	10^6 THB/d	231,697	170,487	0.000	0.000
Total impacts	10^6 THB/d	231,691	170,479	0.000	0.000
Industrial growth rate					
Target	**%**	**9.7**	**9.7**	**9.7**	**9.7**
With pricing policy	**%**	**9.547**	**7.561**	**0.003**	**0.003**
Impacts	**%**	**-0.153**	**-2.139**	**-9.697**	**-9.697**
Recycled water	**Mm^3/d**	**1.545**	**1.545**	**-**	**-**
Water shortage	**Mm^3/d**	**-0.32**	**0.16**	**-**	**-**

3. To minimize raw water needed to support water demand

This standard concentrates in water resources and environmental viewpoints. By this evaluation standard, case 1 and 2 with 100 % recycled rate are suitable choices. Needed raw water in case 1 and 2 is only 1.73 Mm^3/d to support the production process of industrial sector, however, there is no water shortage only in case 1 with 100 % of recycled rate with water surplus 0.32 Mm^3/d.

4.3.3 Strategic decision making model

Finally, industrial water demand management model was developed with the optimal choice for policy makers. The next interesting question is whether this water infrastructure project should be invested under uncertainty in the future such as risk in demand growth rate. If it should be constructed, how the government manages it under that risk? Strategic decision making model is one of powerful tool to manage the water infrastructure management with these risks.

Figure 4.19 shows possible expected from decision tree in 2 cases; with/without strategic decision making model. In case of with strategic decision making model, most of expected benefits are positive because the model will choose the maximum benefit to keep that selected decision but will ignore the choices of less benefit. For the case of without model, most of them are negative because of loss from too much water in case of low water demand with new water infrastructure and too less water in case of high growth without new water supply system.

If the water demand growth is low in the future, policy maker should stop water supply project and monitor the water trend in the future. In this case, the risk of loss of construction, operation, and maintenance cost was strongly considered. However, if high water demand will occur, the new water infrastructure should be constructed to support higher water demand. In this case, the risk of loss of damage from water shortage will be mainly considered.

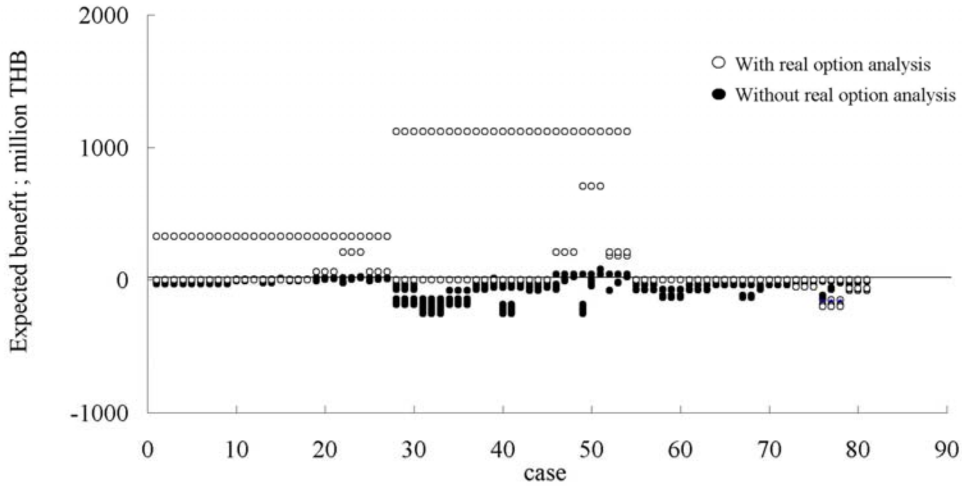


Figure 4.19. Possible expected benefit from decision tree.

Figure 4.20 shows annual net possible expected benefit from 2016 to 2025. It shows how policy maker make decision about new water infrastructure at the starting point of the project. It is almost certain that the water supply project should be invested with strategic decision making system because there is benefit from this project or positive benefit. In the other way, this water project should not be built if decision making system is not applied because of negative benefit. The main reason why decision making system should be applied is policy makers can choose the best way or maximum benefit in each water demand growth rate and decision.

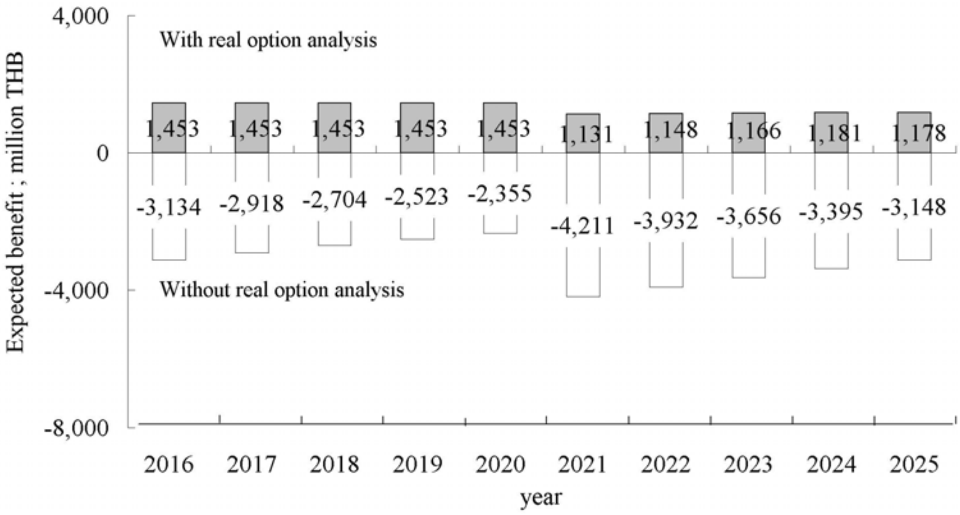


Figure 4.20. Annual net possible expected benefit from decision tree.

4.4 Summary

Proposed industrial water demand management model can predict industrial water demand by using input-output table to analyze the changing industrial structure by the scenarios of Thailand economic growth rate, economic scenarios such as declared Thai industrial master plan as internal effect, and free trade agreements with other countries such as U.S., China, and Japan as external effects. From these conditions, industrial sector need more water to support economic target of Thai government.

Water use unit was calculated with possible maximum recycled rate in each ISIC code form case of Japan. Water supply was simulated with constraints of new supply systems and constraint of price and quantity in each water source. The governmental option and impacts from declared policy were calculated by using cost-benefit analysis with data of analyzed water demand and supply. In this chapter, the suitable government option (evaluation standard 1 and 2) is that government agencies should subsidize the higher water cost and construct the new water infrastructure. The minimum impact from proposed option is -0.153 % from the industrial target of 9.7 % in case of 100 % rate of recycled water. Finally, strategic decision making model should be applied in consideration of water infrastructure project with uncertainly of water demand growth rate in the future.

Targets of Gross Domestic Product by normal growth used in this research were analyzed from the past data. The target is high comparing with Japan case. From this reason, the water demand in study area is higher also. In the planning step, policy makers should carefully edit the target with economic monitoring system because the changing target of economic will highly affect to water use structure. The target can be increased or decreased in the future by the economic situation in that period.

Demand curves used in this research were analyzed from the groundwater use data with possible condition in the future; however, the details of changed demand curve should be carefully considered in the next research.

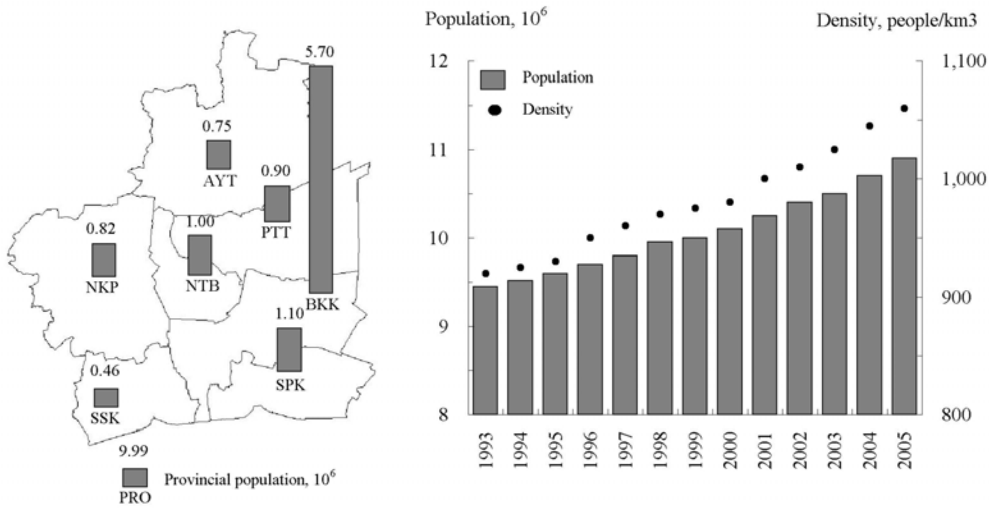
The next interesting topic is how to simulate all of water user sector such as household and agricultural sector into the model and how these activities change by declared policy. How to manage the water share of each user and activity with the changing economics structure from declared policy?

Chapter 5

Household Water Demand Model

5.1 Introduction

Lower Chao Phraya River Basin (LCPRB) is one of the important areas of development in economic and industrial sector in Thailand. Half of Thai Gross Domestic Product or GDP was produced in this area because LCPRB is the central of economic, education, and political process. Not only high economic activities grow in this area, but number and density of population in this area increase also as shown in Figure 5.1. An increase in demand from high density and growth rate of population in this area is likely to cause a rise in need of infrastructure especially water in household water use.



(a.) Map of Study area (b.) Provincial population and density

Figure 5.1. Study area, population and density.

(Source: DOPA.)

From chapter of industrial water demand model, not only industrial activities changed from declared government strategy, but at the same time household water demand got impacts from this policy also, such as, changed daily life style with higher income from higher GDP per capita, migration from the other provinces to have better job opportunity, and etc. Waterworks authority generally calculates household water demand without economic impacts from other sectors, such as, industrial side. This proposed model can forecast household water demand by using population model with varied water use unit per capita in the future.

The objectives of this chapter are shown as follow;

1. To develop population model in details of sex, year, and provinces with scenarios of birth and death by using Cohort-component method and migration model with impacts from changing economic structure from Input-output table model.

2. To develop water use unit model in base case or constant rate in the future and varying unit rate from changing daily lifestyle from higher GDP.

3. To analyze water demand-supply curve from secondary data of government agencies and questionnaire survey including constraints of each water source in each province.

4. To develop integrated water management model including government option scenarios; with/without leakage reduction system, and case of with/without subsidy from governmental side to select the optimum scenario for policy maker to make decision with water demand management system by using equilibrium analysis, pricing policy, and cost-benefit analysis.

5. To develop strategic decision making system for uncertainly (high, medium, and low water demand growth) of infrastructure investment (to construct all infrastructure in the starting point, step by step, or do nothing) in the future.

5.2 Model Structure and Formulation

The model mechanism of household water demand management model developed by using GAMs language is shown in figure 5.2. The model was divided into four parts; water demand, water supply, integrated water management model, and Strategic decision making with uncertainly for infrastructure development. (SUTTINON, P., 2006, 2007).

Firstly, household water demand model was developed in Lower Chao Phraya River Basin, Thailand. There are two main part in this model; (1) Population model, and (2) Water use unit model. Population model by age, sex, and 76 provinces was developed by using Cohort-component method.

Secondly, water demand and supply in each source with price, constraint of quantity, and quality were collected by primary data, and secondary data. These data are important to generate water demand-supply curve in the next step.

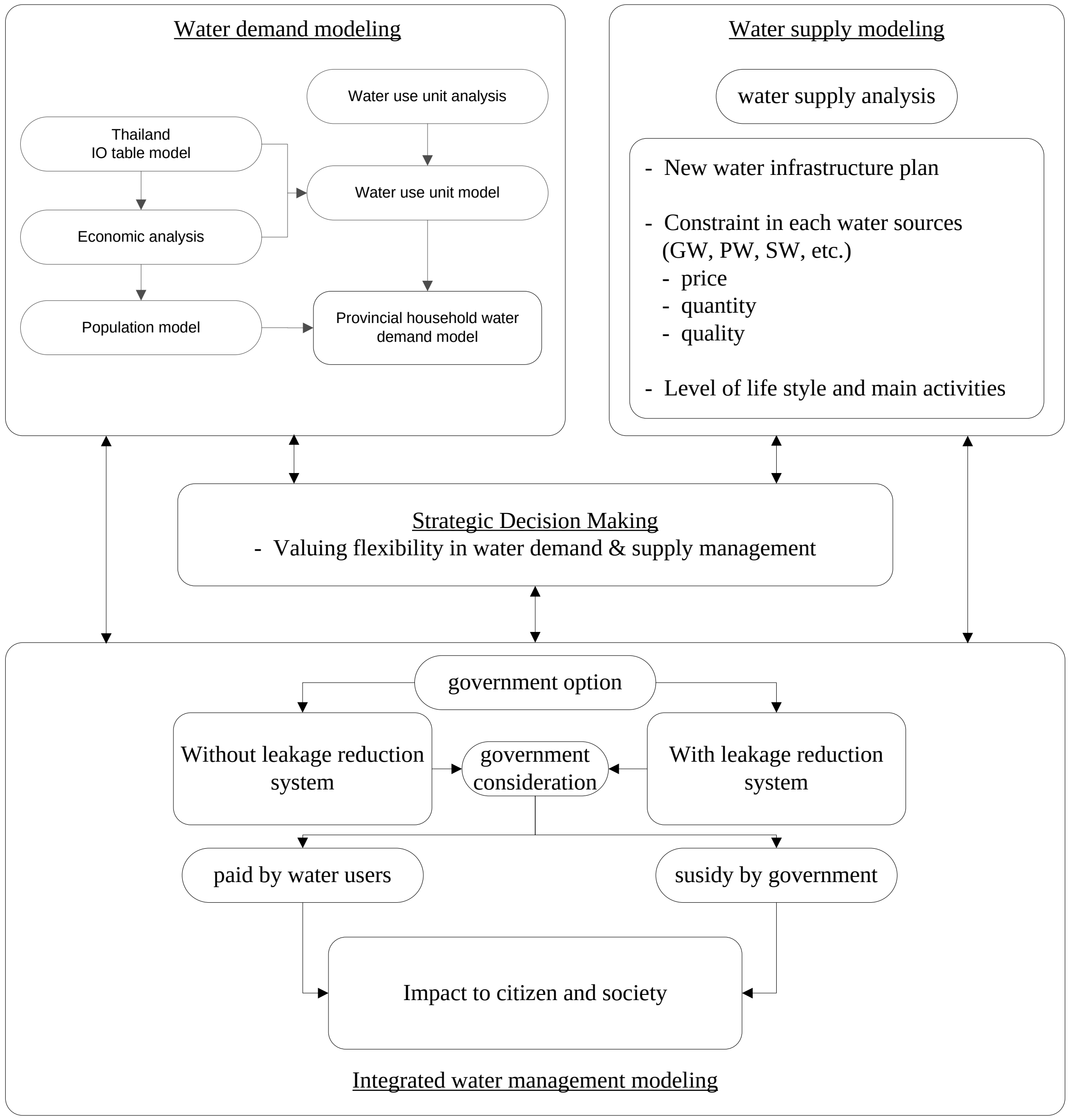


Figure 5.2. Model mechanism.

Thirdly, integrated water management model in case of governmental options was analyzed by using outputs from water demand and supply models. There are 2 main topics for scenarios as follow; (1) with/without leakage reduction system, (2) with/without subsidy cost from governmental agencies. The net benefits of each scenario can be calculated by using this water demand management model. Policy makers can choose the suitable strategy by each evaluation standard.

Finally, after assessment of possible demand and supply, strategic decision making model was applied to analyze whether and how the new water infrastructure should be invested to support the water demand with uncertainty of water demand in the future.

The schematic diagram of household water demand and management model developed is shown in Figure 5.3.

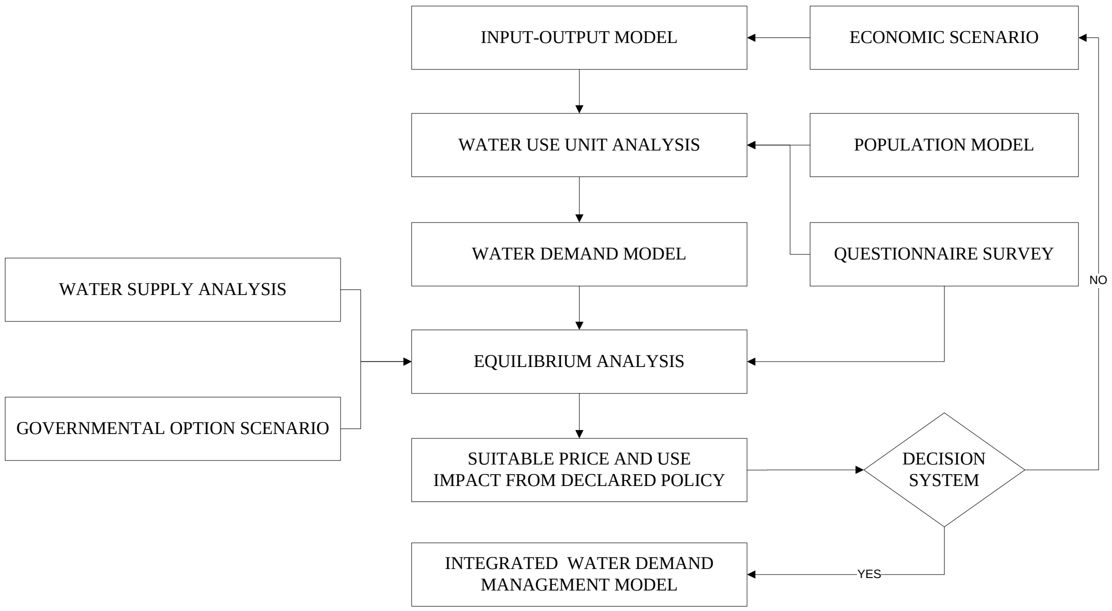


Figure 5.3. Schematic diagram.

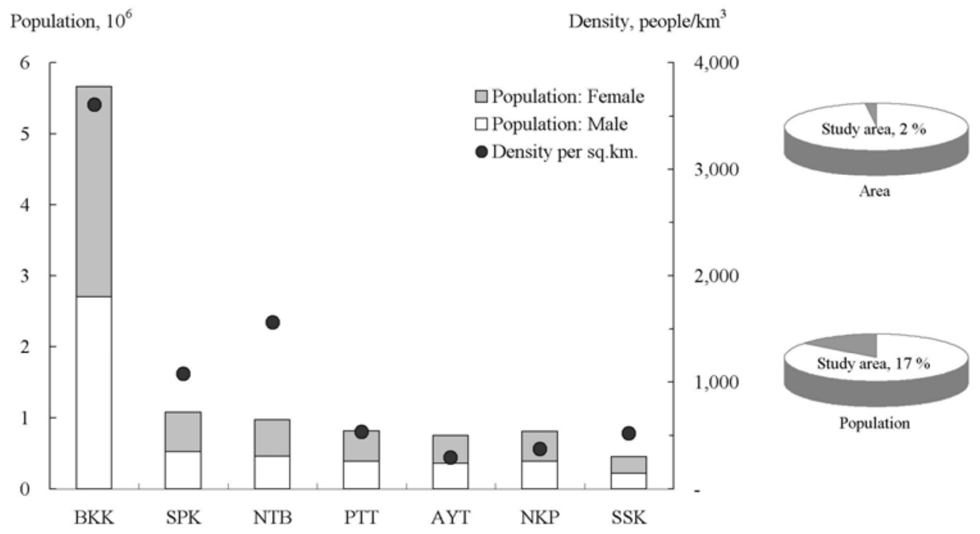
5.2.1 Water demand model

Population model

Figure 5.4 shows base year data of study area in 2005. There are 7 provinces; Bangkok (BKK), Samut Prakarn (SPK), Nonthaburi (NTB), Pathum Thani (PTT), Ayutthaya (AYT), Nakhon Pathom (NKP), and Samut Sakhon (SSK). Bangkok is the highest population province approximately 6 million people with density 3,700 people per sq.km. There are 17 % of total Thai populations live in this study area which is only 2 % of area of Thailand.

Firstly, Population model was developed by using Cohort-component method in format of GAMS language. The cohort-component method is based on the traditional demographic accounting system. With a base population in a starting year, new births are added to the updated population, new death are subtracted to generate a new cohort in next year. Not only birth and death are calculated, but migrations in international and domestic scales are also measured.

Each component of changed population is separately analyzed by age, sex, and each province as follows: $P_t = P_0 + B - D + M$, where, P_t is population at the end of the calculated period, P_0 is population at the starting of period, B is new births, D is new deaths during period, and M is migration including international and domestic. In this analysis, international migration was assumed to zero because of small ratio comparing with provincial scale.



(a) Population and population density (b) Ratio with Thailand

Figure 5.4. Statistical data of population in 2005.

(Source: DOPA.)

Base population data was collected in full demographic detail; age (0,1,2,…,100 and over), sex (male-female), net migration (people in and out) and 76 provinces from Department of Provincial Administration of Thailand or DOPA, Cohort-component was measured in provincial scale. New birth rate was calculated by using data of Age-Specific Fertility Rate (ASFR) in Table 5.1 and Total Fertility Rate (TFR) in Table 5.2 from government agencies.

Table 5.1. Age-Specific Fertility Rate (ASFR) in 2005

	ASFR							TFR
	15-19	20-24	25-29	30-34	35-39	40-44	45-49	
2005	0.06429	0.10680	0.09797	0.05903	0.02409	0.00598	0.00108	1.79620

(Source: DOPA.& NESDB.)

The birth scenarios are 3 scenarios; high, medium, and low TFR. Next, deaths are analyzed in scenarios of with and without effect from AIDS in form of life expectancy in each age as shown in Table 5.3. Finally, net migration was calculated by using regression analysis as following parameter; 1) population growth rate, 2) population density, 3) gross provincial domestic (GPP), 4) GPP per capita, 5) income per capita, and 6) expenditure per capita. Changing economic structure in the future was calculated from IO table model with selected scenarios of declared governmental strategy.

Table 5.2. Total fertility rate (TFR) in each area

	Total	Bangkok	Vicinity	Central	East	West	North	Northeast	South
1990	2.2800	1.3000	1.5900	1.9730	2.0000	2.0400	1.9800	2.7800	2.8500
2000	1.8223	1.1700	1.2300	1.6400	1.6300	1.6900	1.7600	2.1500	2.2500
2025									
High	2.0500	1.3162	1.3837	1.8449	1.8337	1.9012	1.9799	2.4186	2.5311
Med	1.7000	1.0915	1.1475	1.5299	1.5206	1.5766	1.6419	2.0057	2.0990
Low	1.3000	0.8347	0.8775	1.1700	1.1628	1.2056	1.2556	1.5338	1.6051

(Source: DOPA.& NESDB.)

Table 5.3. Life expectancy in each age.

Age	2006				2025			
	With AIDS		Without AIDS		With AIDS		Without AIDS	
	Male	Female	Male	Female	Male	Female	Male	Female
0	0.9675	0.9772	0.9705	0.9862	0.9917	0.9904	0.9922	0.9932
10	0.9959	0.9983	0.9964	0.9986	0.9976	0.9984	0.9978	0.9989
20	0.9924	0.9931	0.9930	0.9973	0.9942	0.9971	0.9948	0.9980
30	0.9829	0.9866	0.9912	0.9952	0.9918	0.9936	0.9939	0.9967
40	0.9662	0.9854	0.9812	0.9888	0.9838	0.9871	0.9863	0.9923
50	0.9455	0.9699	0.9509	0.9733	0.9620	0.9778	0.9641	0.9817
60	0.8783	0.9240	0.8801	0.9321	0.9120	0.9475	0.9127	0.9551
70	0.7150	0.7800	0.7158	0.8002	0.7752	0.8409	0.7755	0.8609
80+	0.3576	0.4030	0.3580	0.4227	0.4194	0.4637	0.4196	0.4837

(Source: DOPA.& NESDB.)

In this research, household water demand was divided into 2 parts; urban area and rural area. The definition of each area in this research is shown as follow;

(1) Urban area is the area inside responsibility area of municipality,
(2) Rural area is the area outside responsibility area.

By the Act of Municipal shown in box 1, municipality or urban area in this area have to provide safe water or pipe water to support the citizen in service area. From this reason, it is recommend that people in urban area has enough water from governmental supply system.

Box 1. The Act of Municipal.

By the Act of Municipal 1953 and 1999 (No. 10), municipal area was divided into 3 types as follow;

(1) Section 9: District municipality ("Tedsaban Tumbon" in Thai language) is the area declared by Ministry of Interior.
(2) Section 10: Town municipality ("Tedsaban Muang" in Thai language) is the area with population more than 10,000 persons and basic needed infrastructures declared by the Act.
(3) Section 11: City municipality ("Tedsaban Nakhon" in Thai language) is the area with population more than 50,000 persons.

Section 51 of the Act of Municipal declared that municipality has to provide safe water or pipe water to support the citizen in the municipal area.

Water use unit analysis

Water use unit analysis is the main activities in the first step of water demand management model. For household sector, water use per capita per day was analyzed from each activity in daily life of citizen in this study area.

Firstly, number of questionnaire sample was designed by statistical analysis with 95 percentage significant level. 400 samples of household questionnaire were needed to analyze. However, sending questionnaires were 2,000 samples because of 20 percentages of response rates. The number of sample in each province was weighted again with number and density of population in 7 provinces. Figure 5.5 shows the map of Thailand and scatter of questionnaire survey in household survey. Bangkok is the main target of this survey because high density of population.

Household questionnaire survey used in this research was developed to analyze water use in urban area. For water use unit in rural area, the constant rate of water use is 50 liter per capita per day defined by Rural Development Information Center of Community Development Department (CDD, 2007).

Household questionnaire survey

There are 3 main topics in this household survey. The questions are as same topic as industrial sector but details are different. The first topic is water use and source. Monthly water use in average and maximum rate, water price, initial cost for investment, problem, and solution are collected in this topic. Water sources consist of tap water, groundwater, and surface water (pond, river, irrigation canal or natural canal).

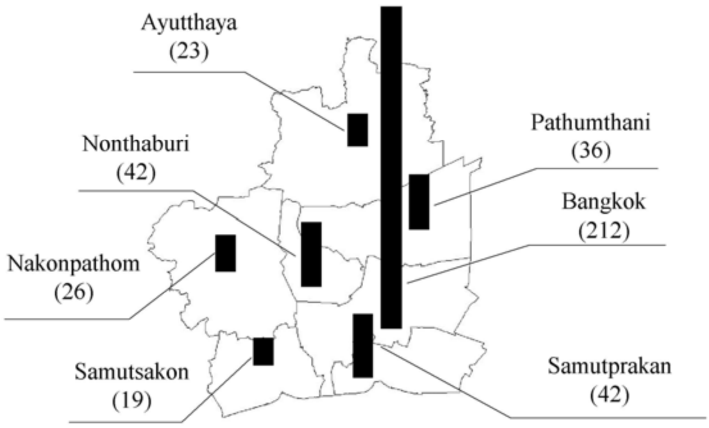


Figure 5.5. Scatter of household questionnaire samples.

In the second part, water use in each activity is collected, for example, the water use, duration, and facility in bathroom, toilet, laundry, cleaning, garden, and kitchen. The third part is concentrated in changing water source from the past, water use situation, reason to choose pipe water, changing water use with suitable price, and water saving policy.

5.2.2 Water supply model

Water demand and supply in each source with price, constraint of quantity, and quality were collected by secondary data (annual report and master plan from government agencies), and primary data (questionnaire survey of Kochi University of Technology). These data are important to generate water demand-supply curve in the next step.

Supply curve was analyzed from master plan and report of Waterworks Authority. There are three sources in this area; groundwater (GW), surface water (SW), and pipe water (PW). Groundwater was limited by groundwater law to protect land subsidence. The yield point of GW in this study area is 1.25 Mm^3/d (Buapeng, S., 2006) but 0.00 Mm^3/d for raw water produced to household sector. (MWA, 2006.) From the problem of quality of water or unsafe water in lower Chao Phraya River, the model was developed under assumption that water source for household in the future is mainly pipe water.

5.2.3 Integrated water management model

Integrated water management model in case of governmental options was analyzed by using outputs from water demand and supply models. Four scenarios generated in this step were shown in Table 5.4; (1) ‘Inf-NoLeak-NoSub’ is case of providing new pipe water (Inf) without leakage reduction system (NoLeak) and without subsidy cost (NoSub) from governmental agencies, (2) ‘NoInf-Leak-NoSub’ is case of with leakage reduction system from 30 % (MWA, 2006) to target of 10 % of leakage rate (Leak) and without subsidy, (3) ‘NoInf-Leak-Sub’ is case of with leakage reduction system and subsidy, and (4) ‘NoInf-Leak-Sub*’ is as same conditions as case 3 but the objective of case 4 is to find the price of raw water which is bought from Royal Irrigation Department (RID) that leakage reduction system will be effective.

Table 5.4. Scenarios of governmental options’ and pricing policy.

Option/scenarios	1. Inf-NoLeak -NoSub	2. NoInf-Leak -NoSub	3. NoInf-Leak -Sub	4. NoInf-Leak -Sub *
New water supply	With	Without	Without	Without
Leakage reduction system	Without	With	With	With
Subsidy	Without	Without	With	With

From the groundwater ban law, now, the Metropolitan Waterworks Authority (MWA) has two sources of raw water to produce pipe water. The first is free water from Chao Phraya River with pumping capacity of 5.8 Mm^3/d. The second one is new water with average price 0.30 THB/ m^3 from Mae Klong and Tha Chin River located outside service area of MWA with capacity 1.3 Mm^3/d. With limitation of water supply, water leakage reduction system may be one of the interesting options of water demand side management, however, the unit cost of water with this system is very high if compare with cost of raw water. From that reason, policy maker needs to know what price of paid raw water is suitable to construct water reduction system.

Finally, the net benefits of each scenario can be calculated by using this water demand management model. Policy makers can choose the suitable strategy by each evaluation standard.

5.2.4 Strategic decision making

Strategic decision making model which is a part of household water demand management model was developed by using decision analysis approach to evaluate all expected possible benefits. Figure 5.6 shows decision tree with sequence of decision and chance nodes in 4 time periods or period_ws parameter. Each time period is 5 years. The small circle is chance node indicating an event of uncertain outcome. In this study, there are 3 chance; high, medium, and low demands. Occurrence possibilities in each chance were calculated by using Extended Pearson-Tukey method. By this method, the 5th, 50th, and 95th percentiles of water demand growth rates are assigned probability 0.185, 0.630, and 0.185. The sum of probabilities of all branches emanating from a chance node is one. Figure 5.7 shows cumulative distribution function for water demand growth rate from last 10 years.

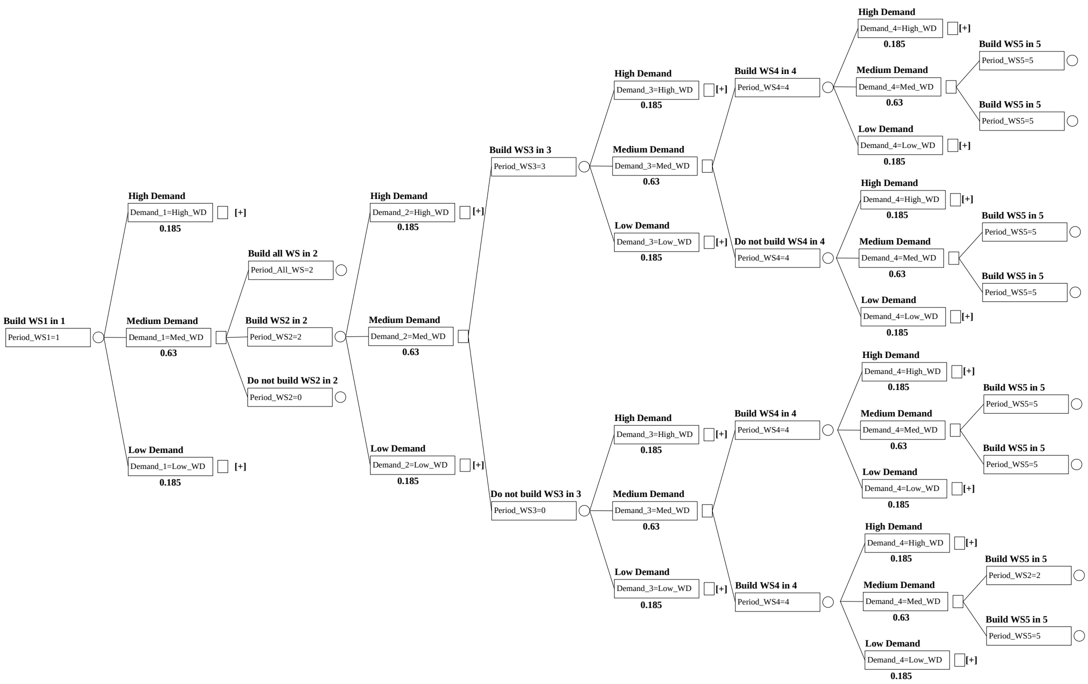


Figure 5.6. Decision tree structure with uncertainties of water demand.

Decision node shown in Figure 5.6 indicates a point where the policy maker faces a decision. In this model, three decisions were presented; 1. To build all water infrastructure, 2. To build step by step, and 3. To do nothing. The last nodes or the ends of the paths denote the final outcome. Each outcome has the combined probability of all chance and it represents the possibility of that possible choice.

Expected benefits of each final path of decision tree were solved from right to left or backwards. Firstly, the values of final node were calculated by difference between benefit from using supported water and loss from excess water. However, the upper limit of using water is save yield point of water supply in each source. The expected benefits of each period were the weighted average of the payoff in its branches by each branch's probability.

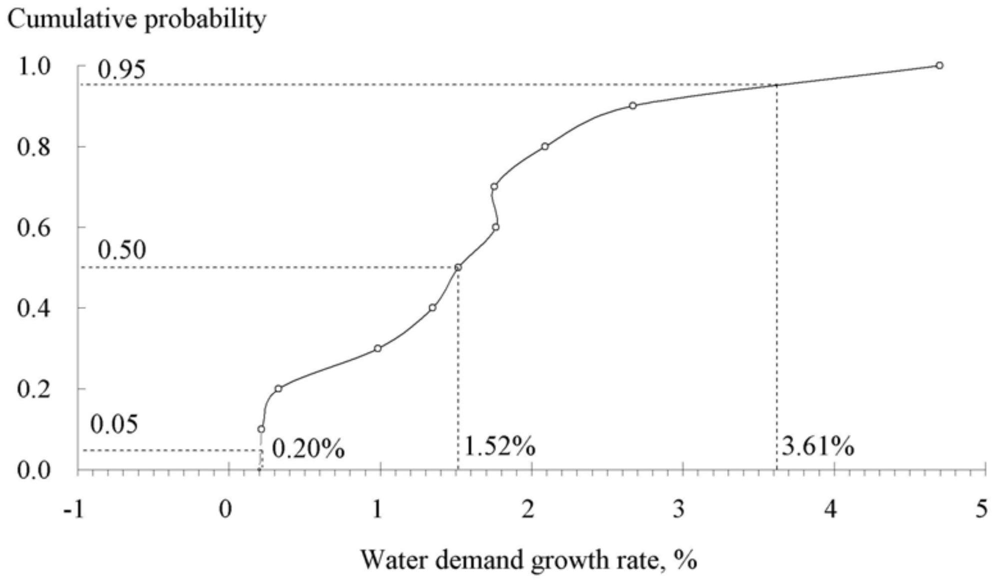


Figure 5.7. Cumulative distribution function for household water demand growth rate.

Finally, net expected benefit of the project was the weighted average of the outcome of all paths by their possibilities.

5.2.5 Model formulation

From the previous topics, four models (water demand, water supply, integrated water management, and strategic decision making model) were developed as household water demand management model by using GAMs language.

This model was designed to run with the same order as schematic diagram shown in Figure 5.8 as follow;

1. Water demand model; Thailand and provincial Input-Output (IO) table model with economic scenarios, population model, water use unit analysis, and water demand model
2. Water supply model; demand-supply function and equilibrium analysis
3. Integrated water management model; governmental option scenario

4. Strategic decision making model

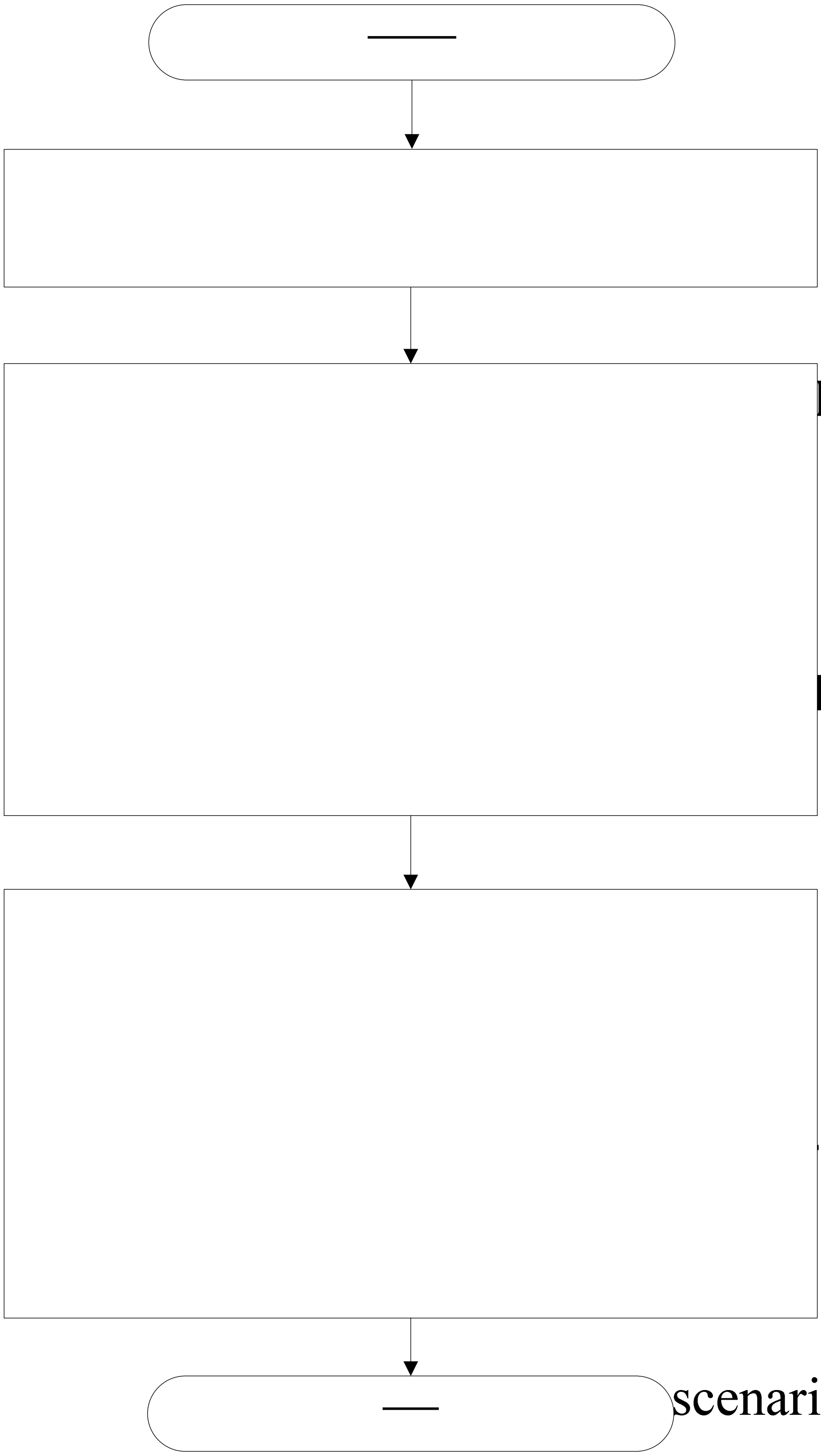


Figure 5.8. Schematic diagram of household water demand management model

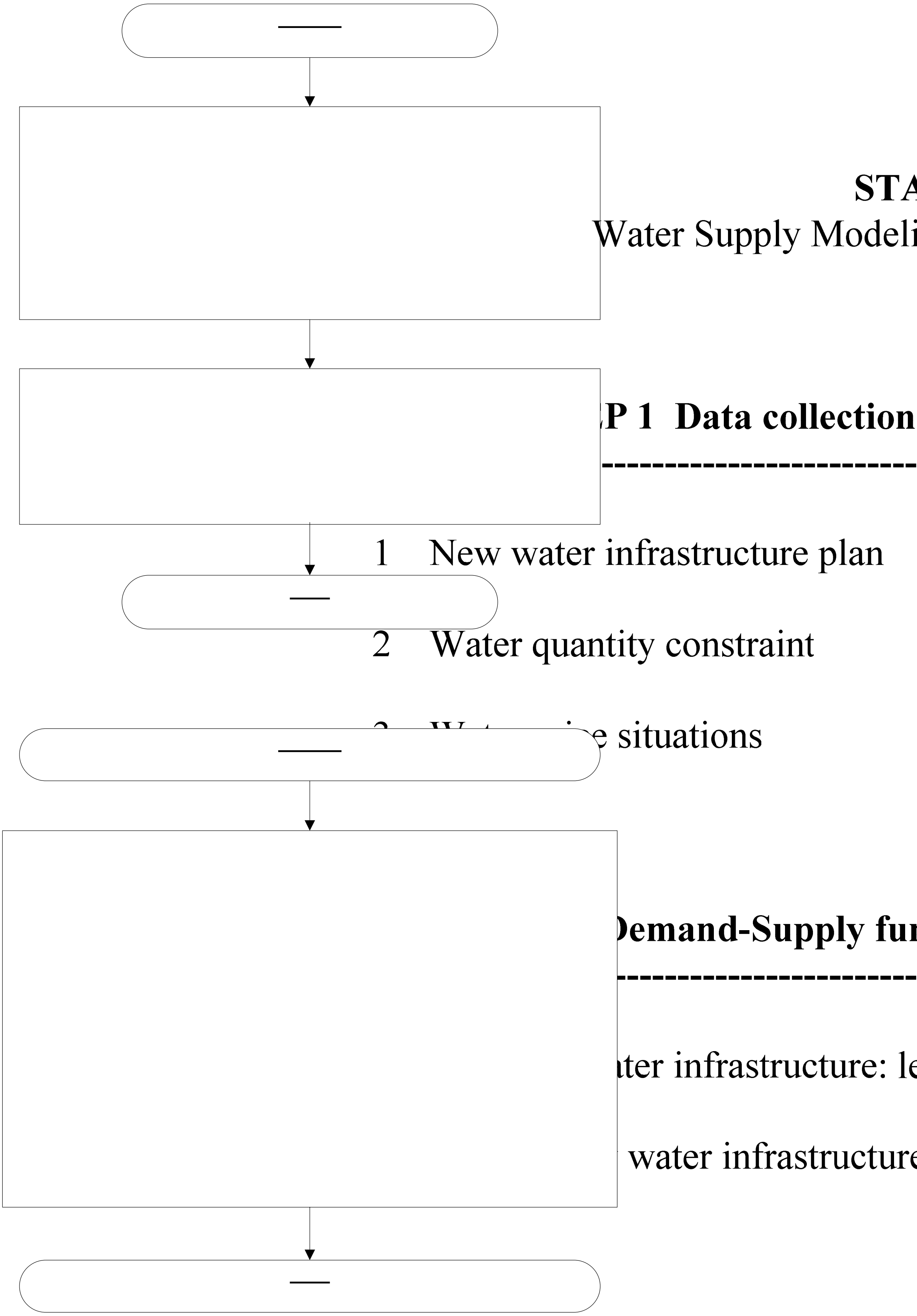


Figure 5.8. Schematic diagram of household water demand management model (Cont'd)

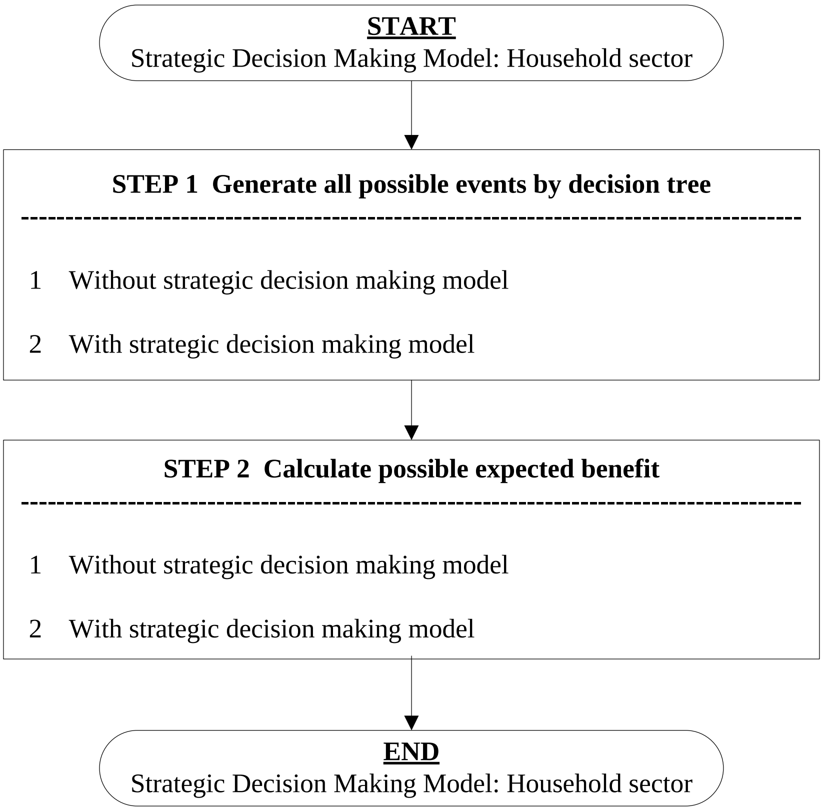


Figure 5.8. Schematic diagram of household water demand management model (Cont'd)

This model was designed as toolbox for policy maker that can update scenarios in engineering, economic, environment, and society in the final process.

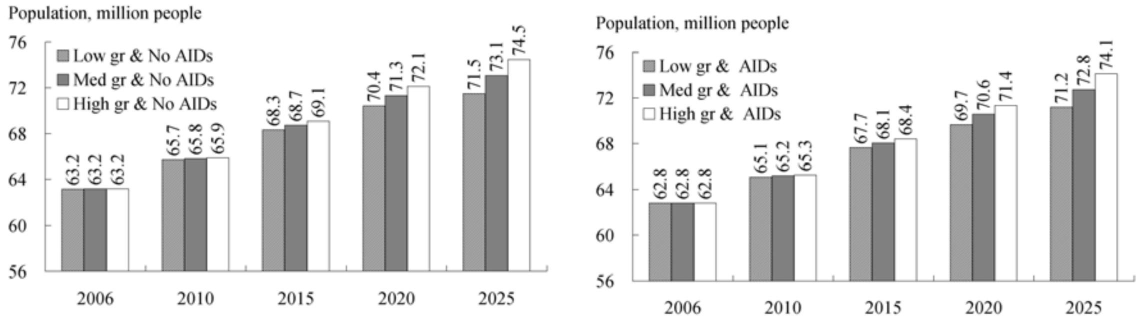
5.3 Household Water Demand Management Model & Results

5.3.1 Water demand model

Population model

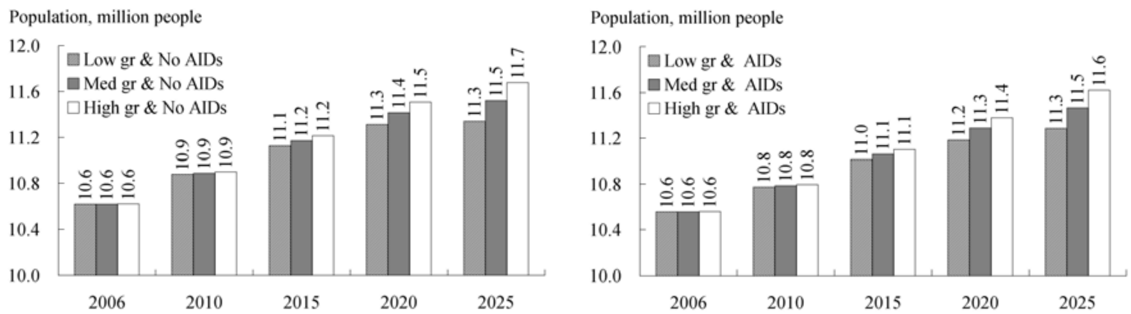
Figure 5.9 shows results from population model in case of Thailand scale. Three scenarios of birth, two scenarios of death, and migration are applied in this model. In case of medium total fertility rate (FTR) and life expectancy with effect from AIDS, there are 72.8 million people in 2025 or 0.78% of population growth rate per year. In case of with and without effect from AIDS with medium FTR, the difference is approximately 330,000 people.

The results in study area as shown in figure 5.10 are as same trend as Thailand scale but the average population growth rate without effect of migration is lower than that case. This low average rate is resulted from the low FTR in Bangkok and Vicinities. In 2025, FTR of Bangkok and vicinities are only 1.0915 and 1.1475 but the average rate of Thailand is 1.7000.



(a) Birth scenarios without AIDs (b) Birth scenarios with AIDs

Figure 5.9. Number of population forecasted from Thailand population model.



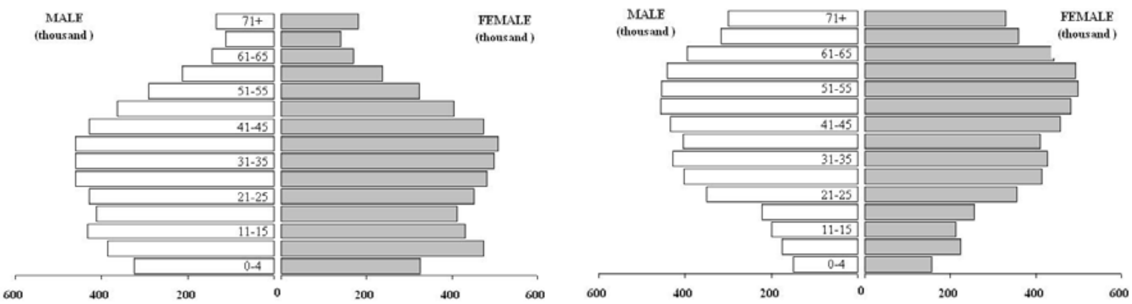
(a) Birth scenarios without AIDs (b) Birth scenarios with AIDs

Figure 5.10. Number of population forecasted from provincial population model.

The average population growth rate without effect of migration in urban and rural area can be compared in case inside and outside study area. That growth rate of urban area including Bangkok and vicinities is approximately 0.434 % that is half of case of outside study area. The reason is different daily life style of urban and rural area. The population per family in big city is gradually decreasing from the past. People need less children, only 1 or 2 persons is suitable in urban daily life style.

Population structure by age and sex in study area was shown in Figure 5.11. It shows that high percentage of number of population in age of 26-50 years will move to the upper part or these people will get older but the new generation was born in the lower rate because people will have small family or 1-2 children per household. The Total

Fertility Rate or TFR in big city such as Bangkok is only 0.83. This rate in Bangkok is less than the average TFR of Thailand with 1.30. The other reason is that life expectancy of old people is higher because of taking care of life and better medical care.



(a.) 2006 (b.) 2025

Figure 5.11. Population structure by age and sex in study area.

Migration model

Migration model was developed in provincial scale with dimension of time series or matrix of 76 X 20 (provinces X years) in forecasting step. Input data was colleted in period of 2000 to 2004 because of incomplete data in some parameter. The migration model was developed by using techniques of time series and cross section pooling. The method is pooled least square in case of fixed effect with no weighting by White Heteroskedasticity-Consistent Standard Errors & Covariance. The equation of migration model was shown in equation 5.1 and coefficient of model in Table 5.5.

Migra(prov,year) = C1*[Pop_gr(prov,year)]
+ C2*[Pop_density(prov,year)]
+ C3(prov)*[GPP(prov,year)]
+ C4(prov)*[GPP_per_capita(prov,year)]
+ C5(prov)*[Income/Expenditure_per_capita(prov,year)]...(5.1)

Where,

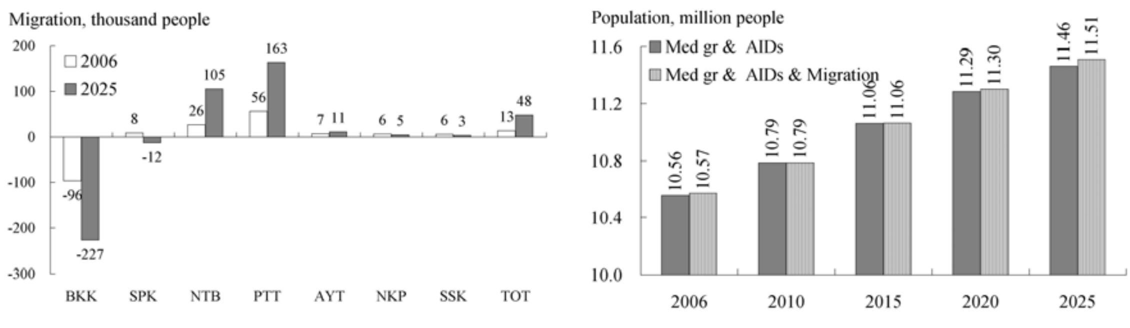
Migra(prov,year)	=	No of net migration (move in – move out) in each province and year
C1,C3(prov)	=	Constant and constant in each province
Pop_gr	=	Population growth in each province and year, %
Pop_density	=	Population density in each province and year, people per sq.km.
GPP	=	Gross Provincial Product at market price,

		million Thai Baht
GPP_per_capita	=	Gross Provincial Product per capita, Thai Baht per person
Income_per_capita	=	Income per capita, Thai Baht per person
Expenditure_per_capita	=	Expenditure per capita, Thai Baht per person

Table 5.5. Variable coefficients and statistic analysis of migration model

Variable	Statistic analysis	
	Coefficient	Std. Error
1. Pop_gr	-2079.408	528.2922
2. Pop_density	38.51234	9.679315
3. GPP		
3.1 BKK	0.565516	0.028027
3.….	….	….
4. GPP_per_capita		
4.1 BKK	-3620109.	175517.5
4.….	….	….
5. Income/Expenditure_per_capita		
5.1 BKK	-51664.16	28462.36
5.….	….	….
R-squared 0.69	Durbin-Watson stat 3.66	

Figure 5.12 shows migration in study area. Net migration of BKK and SPK is negative in year 2025. It means that move out is more than move in because of high density of population, high expenditure from becoming big city with higher GPP. The direction of migration moves to the upper part of Bangkok (BKK) to Nonthaburi (NTB) and Pathum Thani (PTT) that have good public transportation and not far from BKK.



(a) Migration (b) No of population with migration

Figure 5.12. Number of net migration forecasted from provincial population model

The results of sensitivity analysis of migration model was shown in table 5.6. The main parameter are GPP and GPP per capita with high percentage of change from changed variables.

Table 5.6. Sensitivity analysis of migration model.

Variables	Δ% Var	BKK	SPK	NTB	PTT	AYT	NKP	SSK
Pop	10	0.2	3.7	3.2	2.7	0.9	4.6	10.4
	20	0.5	7.4	6.4	5.4	1.8	9.1	20.8
Pop density	10	40.4	49.6	37.8	6.1	15.8	34.6	28.7
	20	80.9	99.2	75.6	12.2	31.6	69.2	57.3
GPP	10	269.5	103.0	66.8	20.1	76.4	233.5	126.4
	20	539.0	206.1	133.5	40.2	152.8	466.9	252.8
GPP per capita	10	300.2	125.5	87.1	21.6	91.4	266.0	159.5
	20	600.3	251.1	174.1	43.2	182.8	532.0	319.1
Income per expend	10	19.5	13.4	44.9	8.1	10.1	12.5	4.9
	20	39.0	26.8	89.8	16.2	20.2	25.0	9.7

Population in Urban and Rural area

Final step of population model is to define population in urban and rural area as shown in figure 5.13. Expansion of urban area was analyzed from the trend in the past from Department of Provincial Administration with the water master plan of Waterworks Authority.

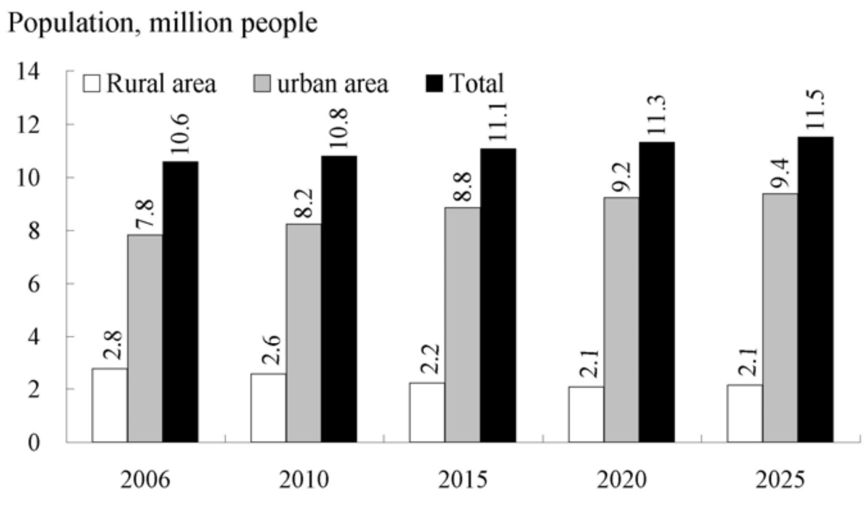


Figure 5.13. Number of population in rural and urban area

Water use unit analysis

Household water use unit was calculated from questionnaire survey of Kochi University of Technology (SUTTINON, P., 2007). Main domestic water source in this area is pipe water or tap water about 83 % in 2006. This high percentage of pipe water is managed by 2 government agencies; Metropolitan Waterworks Authority (MWA) and Provincial Waterworks Authority (PWA). The service areas of MWA showed in black area of the map in Figure 5.14 are only 3 provinces; 1 Bangkok (BKK), 2 Samut Prakan (SPK), and 3 Nonthaburi (NTB), however, MWA take responsibility in 81.4 % of water use in study area. Ayutthaya (AYT), Pathum Thani (PTT), Nakhon Pathom (NKP), and Samut Sakhon (SSK) are service areas of PWA as the white areas.

(a) Water source (b) Service area (c) Water use by agency

Figure 5.14. Household water source and use by process.

Figure 5.15 shows household water use unit in urban area and GPP per capita in service sector. The water use unit in Bangkok and vicinities located in service area of MWA is higher than other areas because of higher water using activities from higher daily life style.

Varied water use unit model was developed in provincial scale with dimension of time series or matrix of 7 X 20 (provinces X years) in forecasting step. Input data was colleted in period of 2000 to 2004 because of incomplete data in some parameter as same as migration model. The water use unit model was developed by using techniques of time series and cross section pooling. The method is pooled least square in case of fixed effect with no weighting by White Heteroskedasticity-Consistent Standard Errors & Covariance. The equation of model was shown in equation 5.2 and coefficient of model in Table 5.7.

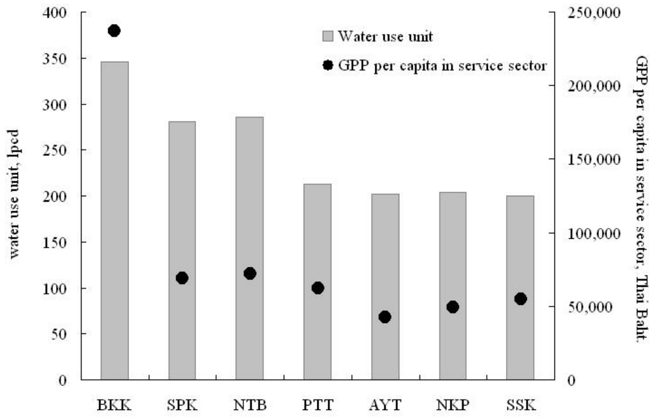


Figure 5.15. Household water use unit in urban area and GPP per capita in service sector in 2006.

LPCD(prov,year) = C1*[PW_pr(prov,year)]
+ C2(prov)* [GPP_per_capita(prov,year)]
+ C3(prov)*[Income_per_capita(prov,year)]………………..(5.2)

Where,

LPCD(prov,year)	=	Household water use unit in each province and year , Liter per capita per day or lpcd.
C1,C2(prov)	=	Constant in each province
PW_pr	=	Price of pipe water, Thai Baht per cubic meter
GPP_per_capita	=	Gross Provincial Product per capita, Thai Baht per person
Income_per_capita	=	Income per capita, Thai Baht per person

Table 5.7. Variable coefficients and statistic analysis of water use unit model

Variable	Statistic analysis	
	Coefficient	Std. Error
1. PW_pr	14.64886	0.955900
2. GPP_per_capita		
2.1 BKK	47.99467	13.83483
2.….	….	….
3. Income_per_capita		
3.1 BKK	26693.04	2876.321
3.….	….	….
R-squared 0.82		Durbin-Watson stat 2.211313

Figure 5.16 shows water use unit and household water demand by provinces in 2025. In case of varied water use unit, provincial water unit totally increased from the base year. The citizen in Bangkok need the highest water unit because of luxury daily life style in big city. At the same time, Bangkok is the highest household water consumer because of a lot of population lived in this area and high water use unit.

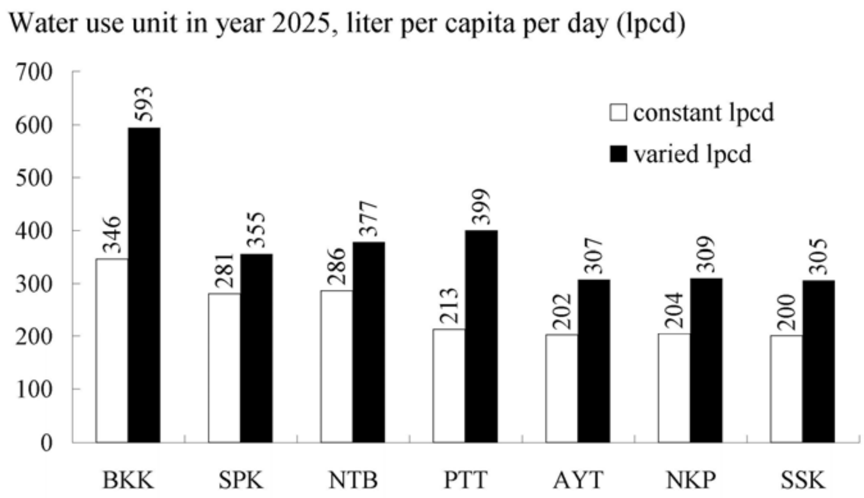


Figure 5.16. Constant and varied water use unit by provinces in 2025

The results of sensitivity analysis of LPCD model was shown in table 5.8. The main parameter is the price of pipe water with high percentage of change from changed variables.

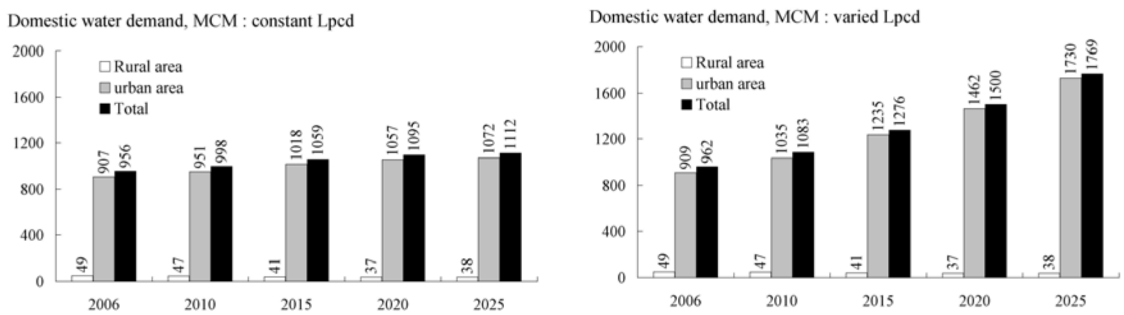
Table 5.8. Sensitivity analysis of water use unit model.

Variables	Δ% Var	BKK	SPK	NTB	PTT	AYT	NKP	SSK
PW_pr	10	5.3	6.5	6.1	10.6	10.6	10.3	5.3
	20	10.7	12.9	12.3	21.2	21.1	20.7	10.7
GPP_per_capita	10	0.5	0.1	0.8	1.2	1.2	1.4	0.5
	20	0.9	0.3	1.5	2.3	2.3	2.8	0.9
Income_per_capita	10	4.2	3.4	3.1	1.7	1.7	1.7	4.2
	20	8.4	6.8	6.2	3.5	3.4	3.5	8.4

Household water demand

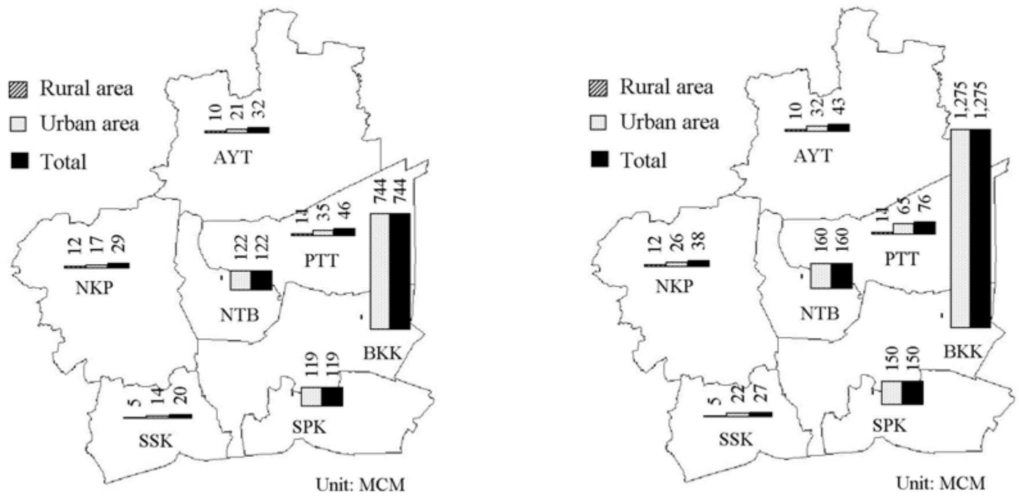
Figure 5.17 shows household water demand of study area in case of constant and varied water use unit from impacts of changing economic activities from Input-output table model. In case of constant water unit, needed household water demand in 2025 will be

1,112 million cubic meter per year. The urban area consumes water more than 90% of total use. In case of varied water unit from changing economic activities is sharply increased in urban area because higher water use unit per capita per day or lpcd as shown in case of Bangkok in figure 5.18.



(a) Constant water use unit (b) Varied water use unit

Figure 5.17. Household water demand in study area.



(a) Constant water use unit (b) Varied water use unit

Figure 5.18. Household water demand in each province in year 2025.

5.3.2 Water supply model and integrated household water management model

Figure 5.19 shows how household water demand and supply curve can simulate with four governmental options' scenarios. The water demand for selected economic and population scenario in 2025 by using water demand model is 1,769 MCM/year or 4.85 Mm^3/d as shown in dash line. Demand curve named D in base year was generated by data from government agencies with analyzed data from questionnaire (SUTTINON, P., 2007). Demand curves in the future were transformed to target demand form model as shown in line named D’ and D’’. The main assumption of this step is water shortage for household sector is unacceptable. It means that household sector was guaranteed by government to have enough water use.

Water supply curve in case 1 was generated from constraints of groundwater and pipe water. The upper limit of GW is 0 Mm^3/d for household sector from the groundwater ban law. The second step is PW1 or the pipe water that was produce from Chao Phraya River. The third period is PW2 with higher price from paid raw water to RID for other rivers. The equilibrium points in case 1 is EP1’; demand at 4.85 Mm^3/d with price of 10.33 THB/m^3.

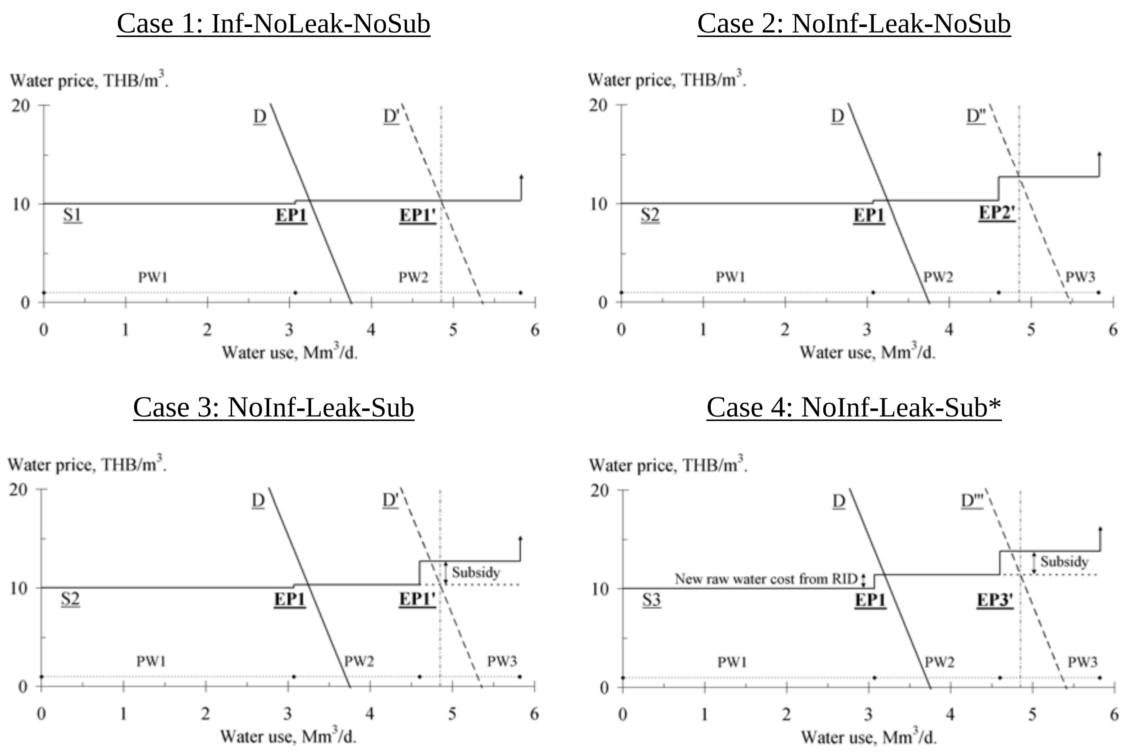


Figure 5.19. Household water demand and supply curve in each scenario.

In case 2 or case of with leakage reduction system, supply curve was shifted higher with additional unit construction, operation, and maintenance cost approximately 2.47 THB/m^3 in period PW3. The equilibrium points name EP1 was shifted to EP2’ at price of 12.7 THB/m^3 with 4.85 Mm^3/d of demand. It means that users have to pay higher cost for the same amount of water in case 1. The satisfaction of users in this case is lower than case 1 because they pay higher price for the same quantity of water.

In case 3, users actually pay for water at 12.7 THB/m^3 with only 4.73 Mm^3/d of water demand that is lower than needed water in case of without subsidy. It means that users have to reduce water use and comfortable life because of higher price; however, if government side subsidizes higher unit cost from leakage reduction system for user, users can get the same satisfaction as case 1 but can save raw water from leakage reduction system.

Case 4 have same mechanism as case 3 but the price of raw water bought from RID is different. The case 4 was generated to calculate what price of bought raw water that water leakage system should be invested.

Table 5.9 shows the results of household water demand management model in case of governmental options' scenarios by benefit-cost analysis. The benefit was calculated from four topics; (1) water sale, (2) consumer surplus, (3) producer surplus, and (4) free water of leakage reduction from 30 % to 10 % of leakage rate. Total costs were analyzed from two topics. The first is subsidy cost and the second is unit cost of construction, operation and maintenance.

Evaluation standard

As same as industrial sector, there is a question for policy makers how to select the suitable governmental options to declare and use. There are many ways to choose the suitable option with constraints in this area. Evaluation standards are the tools for government to make a decision. However, the most important assumption in this household evaluation is that there is no shortage for this sector because water for people is the first priority. It means that basic water infrastructures have to construct to support higher water demand. In this topic, there are 3 evaluation standards used in this study as follow;

1. To maximize net benefit:

This standard is concentrated to choose the governmental option that produce maximum net benefit or maximum of (benefit – cost). Table 5.9 shows that maximum net benefit is case 1 and 4 with total benefit of $290.90*10^6$ THB/d. In case 1, it means that policy maker should construct only the water supply system without leakage reduction system and subsidy. The reason is that unit water price of leakage system is more highly expensive than unit price bought from RID. The advantage of this case is the citizen can use more water as they need with the cheap price; however, the disadvantage is the difficulty of finding new raw water sources.

Table 5.9 Cost-benefits analysis, impacts from governmental options' scenarios and pricing policy.

	Unit	Case 1. Inf-NoLeak -Nosub	Case 2. NoInf-Leak -Nosub	Case 3. NoInf-Leak -Sub	Case 4. NoInf-Leak -Sub *
Water use	Mm^3/d	4.85	4.85	4.85	4.85
Price at equilibrium point	THB/m^3	10.33	12.70	12.70	14.10
Price paid by user	THB/m^3	10.33	12.70	10.33	10.33
Leakage reduction system		Without	With	With	With
Subsidy		Without	Without	With	With
Benefit					
- Water sale	10^6 THB/d	49.18	49.77	49.18	49.40
- Consumer surplus	10^6 THB/d	240.80	229.44	240.80	238.02
- Producer surplus	10^6 THB/d	0.92	11.82	0.92	4.32
- Free water from leakage	10^6 THB/d	0.00	0.04	0.08	0.35
Total benefit	10^6 THB/d	290.90	291.08	290.98	292.09
Cost					
- Construction cost	10^6 THB/d	0.00	0.32	0.59	0.59
- Subsidy cost	10^6 THB/d	0.00	0.00	0.59	0.59
Total cost	10^6 THB/d	0.00	0.32	1.19	1.19
Net benefit	10^6 THB/d	290.90	290.76	289.79	290.90

Note: 1. * for case 4, the net benefit will equal to case 1 if the price of raw water bought form RID is higher than 1.41 THB/m^3

2. 36.3 Thai Baht (THB) = 1 U.S. Dollar (USD) at Dec 22, 2006.

2. To maximize user's satisfaction:

From the previous standard, it is possible that the maximum benefit's choice in case 4 will have a problem of user's dissatisfaction. This standard will concentrate in maximizing user's satisfaction. Case 1 and 3 are the suitable choices for this standard with maximum net benefit. The reason that leakage reduction system is not effective is because the unit cost of raw water is very cheap approximately 0.30 THB/m^3 (average cost of raw water in all rivers) compared with unit cost of leakage reduction system at 2.37 THB/cu.m.

3. To minimize raw water needed to support water demand:

By this standard, case 3 and 4 is suitable choice. Needed raw water in case 3 and 4 is only 4.6 Mm^3/d to produce pipe water or can save raw water more than case 1 approximately 0.25 Mm^3/d, however, the maximum spared capacity is 1.22 Mm^3/d.

As can be seem in Table 5.9, in the viewpoint of central government, if the evaluation standard is maximum net benefit, case 1 and 4 are the suitable because of the highest net benefit. However, the consumer surplus or user's satisfaction in case 4 is lower than case 3's benefit. It means that if user can choose, case 4 is the second choice. It may be affected to society's problem. Policy makers should carefully make a decision with this option under suitable evaluation standard. The net benefit in case 4 is as same as case1 with the raw water price bought from RID at 1.41 THB/m^3 or 4.7 times of price in present. It means that leakage reduction system should be effective with this unit raw water cost.

5.33 Strategic decision making model

Figure 5.20 shows possible expected from decision tree in 2 cases; with/without strategic decision making model. In case of with strategic decision making model, most of expected benefits are positive because the model will choose the maximum benefit to keep that selected decision but will ignore the choices of less benefit. For the case of without model, most of them are negative because of loss from too much water in case of low water demand with new water infrastructure and too less water in case of high growth without new water supply system.

If the water demand growth is low in the future, policy maker should stop water supply project and monitor the water trend in the future. In this case, the risk of loss of construction, operation, and maintenance cost was strongly considered. However, if high water demand will occur, the new water infrastructure should be constructed to support higher water demand. In this case, the risk of loss of damage from water shortage will be mainly considered.

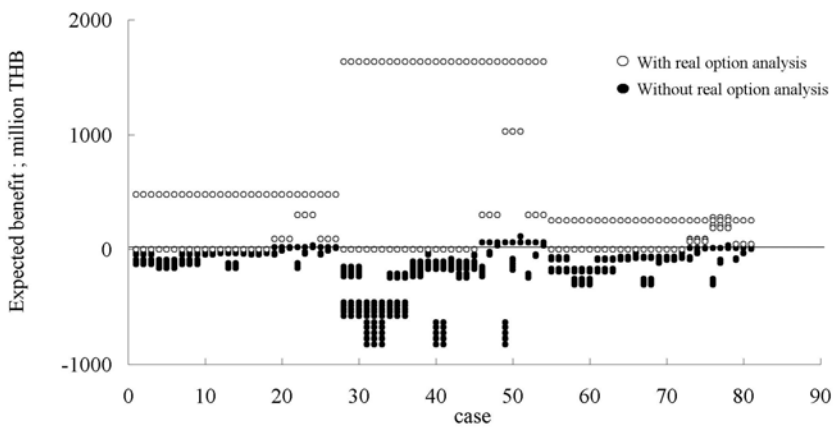


Figure 5.20. Possible expected benefit from decision tree.

Figure 5.21 shows annual net possible expected benefit from 2016 to 2025. It shows how policy maker make decision about new water infrastructure at the starting point of the project. It is almost certain that the water supply project should be invested with strategic decision making system because there is benefit from this project or positive benefit. In the other way, this water project should not be built if decision making system is not applied because of negative benefit. The main reason why decision making system should be applied is policy makers can choose the best way or maximum benefit in each water demand growth rate and decision.

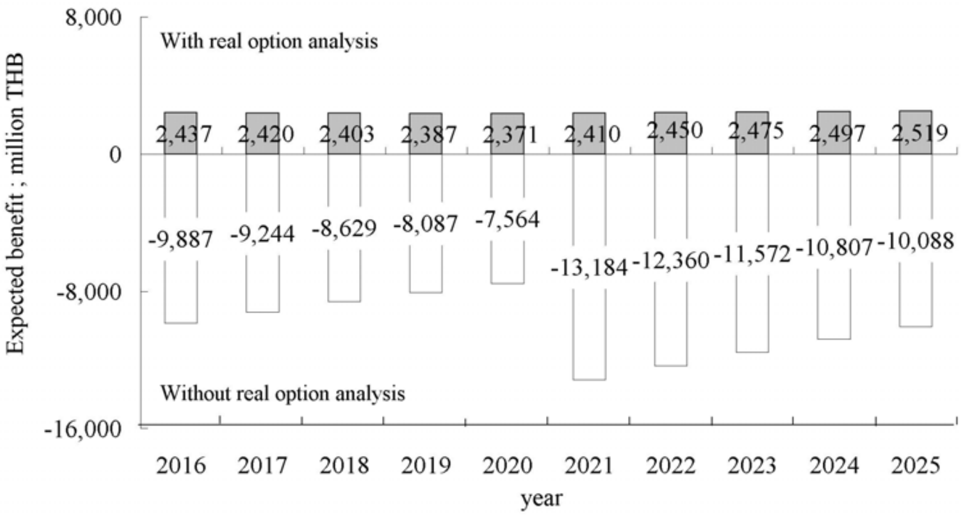


Figure 5.21. Annual net possible expected benefit from decision tree.

5.4 Summary

Proposed household water demand management model can predict household water demand by using population model from Cohort-component model and water use unit from analyzed data from questionnaire survey of Kochi University of Technology in 2006. Three case of total fertility rate (high. Medium, and low), two cases of deaths (with and without effects from AIDS), and migration from changing economic structure from Input-output table were applied in this model. Water use unit in the future was analyzed from questionnaire survey and impacts from changing economic structure from Input-output table. Water supply was simulated with constraints of new supply systems and constraint of price and quantity in each water source. The governmental option and impacts from declared policy were calculated by using cost-benefit analysis with data of analyzed water demand and supply. In this chapter, the suitable government option is considered with evaluation standard. Finally, strategic decision making model should be applied in consideration of water infrastructure project with uncertainly of water demand growth rate in the future.

Demand curve in household sector should be carefully considered as same as industrial case. Policy makers should generate demand curve in the future with the condition in that period. Migration is one of the main effects to rapidly increasing/decreasing population. In Thailand, most unskilled-labor comes from the agricultural sector in rural area. Changing economic strategy especially industrial will affect to migration factor also. Policy makers should consider this impact because moving of production base or changing industry type will change the structure of labor in that area.

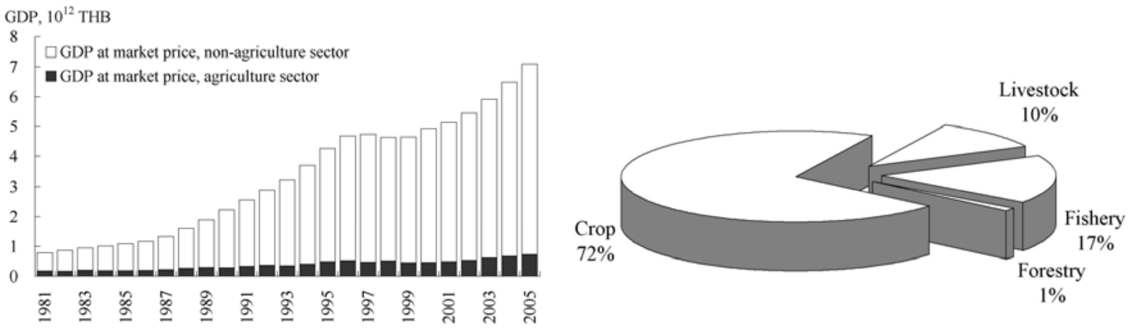
The next interesting topic is how to simulate agricultural sector into the model and how these activities change by declared policy and how to manage the water share of each user and activity with the changing economics structure from declared policy?

Chapter 6

Agricultural Water Demand Model

6.1 Introduction

Thailand is basically agricultural country. Most people located in rural area mainly work in irrigation activities. From this reason, agricultural sector is one of the important economic activities in Thailand. Gross Domestic Product or GDP growth rate in agricultural as shown in figure 6.1 is low comparing with non-agricultural sector because of master plan concentrated industrial and service development in the past. However, GDP growth rate in this sector is constant even in the economic crisis in year 1997. In that period, industrial sector faced the high impacts with critically decreased GDP growth rate. After the economic crisis, Thai government carefully concentrates in agricultural sector again as shown in some strategy of the 9th and 10th national economic and social development plan.



(a.) Gross domestic product (b.) Percentage of agricultural GDP

Figure 6.1. Gross Domestic Product in agricultural and non-agricultural sector.

(Source: NESDB)

Agricultural sector is main part of export value in Thailand with approximately 20 % as shown in table 6.1 and 6.2. In the world, Thailand is the main exporter of agricultural product as following; the 1st order in rice, cassava, and maize; the 4th order in sugarcane (FAO). Thailand declared national master plan name “Thailand is the kitchen of the world” in the 9th national economic and social development plan. From this policy, food and beverage products were concentrated with higher demand of raw material from agricultural sector.

Table 6.1 Export value of Thailand

Unit: Thousand million THB.

Export value	2001	2002	2003	2004	2005	Growth,%
Total	2,885	2,924	3,326	3,875	4,437	12.10
Agricultural sector	684	694	804	886	940	9.19
- Agricultural prod.	533	533	623	677	704	8.27
- Agri-industrial prod.	89	93	110	127	151	14.79
- Forestry prod.	63	68	71	83	84	8.25

(Source: The Customs Department)

Table 6.2 Export value of main agricultural product

Unit: Thousand million THB.

Export value	2001	2002	2003	2004	2005	Growth,%
Total rice	70	70	77	108	94	10.66
Cassava prod.	23	23	27	35	34	13.07
Sugar and prod.	35	34	45	38	35	0.59
Rubber and prod.	109	132	185	222	251	4.72

(Source: The Customs Department)

Figure 6.2 shows trend and effect of urbanization in Thailand. Now, rural area is decreasing and changing to urban area. It is almost certain that there is movement of labor from agricultural sector to non-agricultural sector because of better salary without uncertainty of climate.

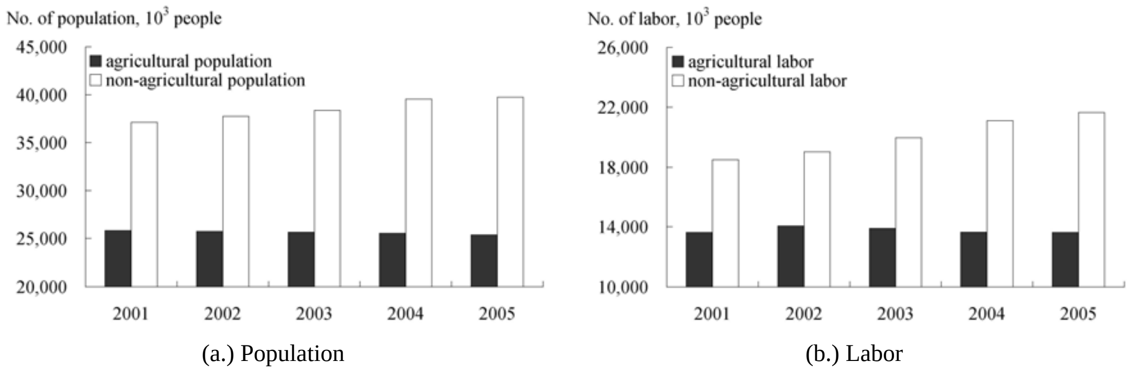


Figure 6.2. Population and labor in agricultural and non-agricultural sector.

(Source: NESDB)

In the viewpoint of water use, agricultural activities consume much water especially rice which is main crop of Thailand. Only 1 % of consumed water in this sector is a big amount of water in industrial and household sector. Policy makers should carefully consider this part with the other users. Water share from one sector to another is very sensitive. It may change the water shortage problem to bigger problem as society and political problem.

The main objective of this chapter is to develop agricultural water demand model by using input-output model to calculate effects from changing economic structure with the effect of climate factors.

6.2 Model Structure and Formulation

The model mechanism of agricultural water demand management model developed by using GAMs language is shown in figure 6.3. The model was divided into two parts; irrigation and livestock water demand.

Irrigation water demand

Firstly, irrigation water demand model was developed in national scale to calculate main crop area affected form world market and domestic market in Thailand with Input-output table model. Secondly, main crop area in each province was calculated from economic structure with trend of Thailand under constraints of possible agricultural area, irrigation service area, and soil condition. Thirdly, water use unit in each crop was analyzed with climate effect under uncertainty of rainfall in the future. Finally, irrigation water demand was calculated from forecasted main crop area and water use unit per area.

Livestock water demand

Livestock sector is very low percentage if comparing with irrigation sector but the important point is environmental viewpoint. Wastewater from livestock in high density area such as Nakon Pathom is interesting topic for policy makers. The forecasting method in this sector is basically trend analysis form the data in the past. Water use unit per livestock was collect from Department of Livestock Developement. Finally, livestock water demand was calculated from forecasted number of each livestock and water use unit per head.

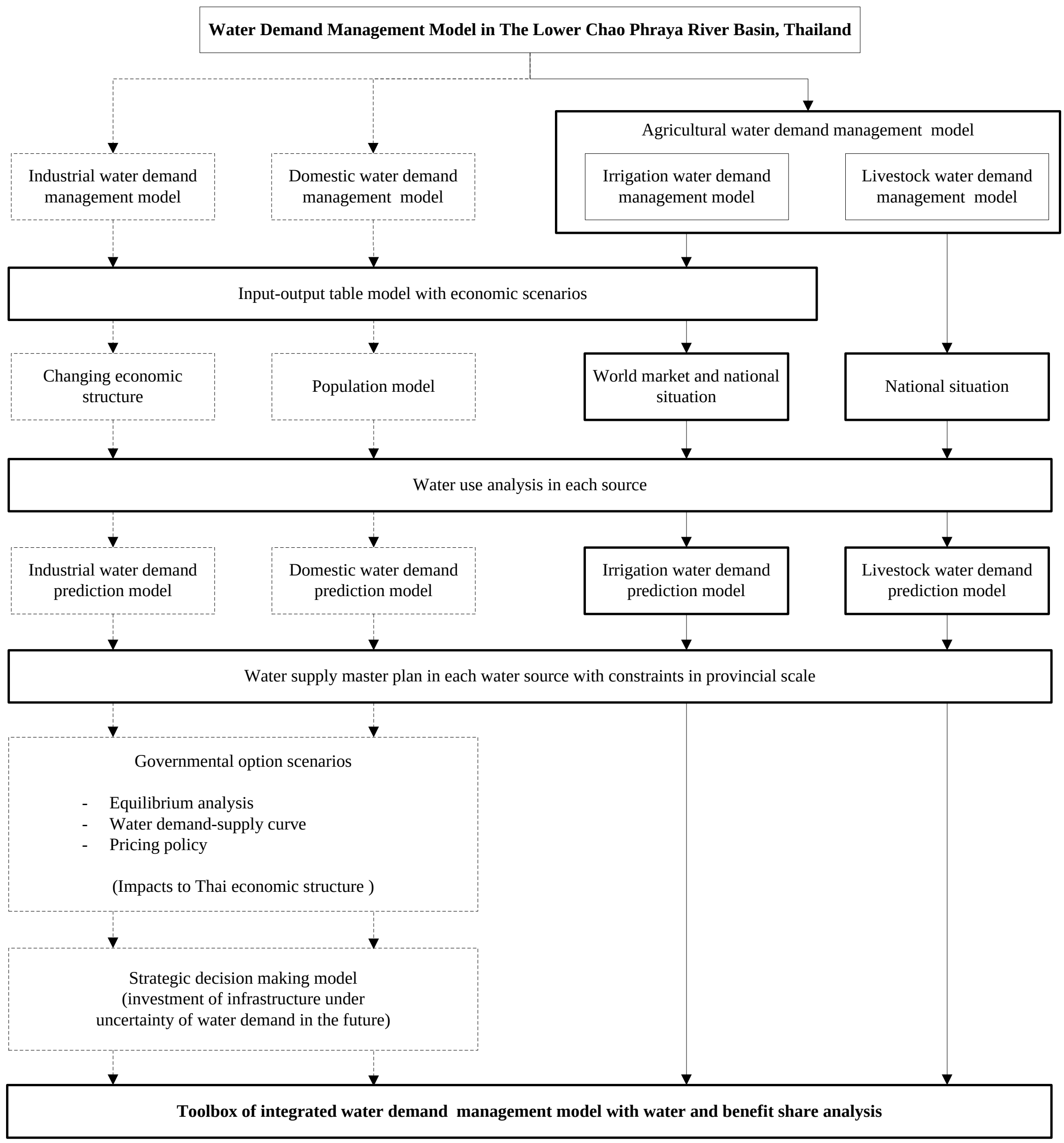


Figure 6.3. Model mechanism.

6.21 Irrigation water demand model

Irrigation water demand can be estimated by using the following equation:

$$WD_{crop} = (ET_{crop} - P_e) * A_{crop} \qquad (6.1)$$

Where,

WD_{crop} is irrigation water demand

ET_{crop} is the water requirement in each crop

P_e is effective rainfall

A_{crop} is the crop area

Crop area model

Firstly, crop area was analyzed in 2 step; (1) Thailand scale and (2) Provincial scale. Crop area in Thailand scale was analyzed with world market situation and national market situation. Provincial crop area was calculated from provincial irrigation activities with constraint of possible agricultural area, inside-outside irrigation service area, and physical condition of soil types. However, crop information in world, national, and province should be considered with constraints in each level.

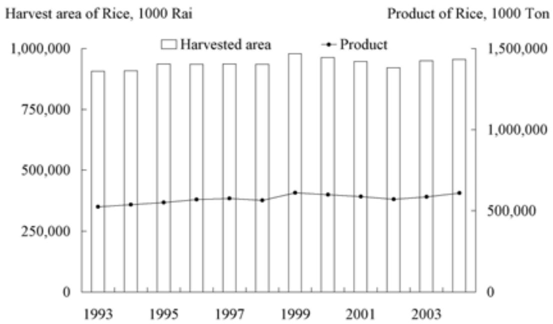
World situation

World situation of agricultural was considered because Thailand is the main exporter in the world. From this reason, the main effects of irrigated demand from Thailand were 2 factor; (1) world market, and (2) domestic market.

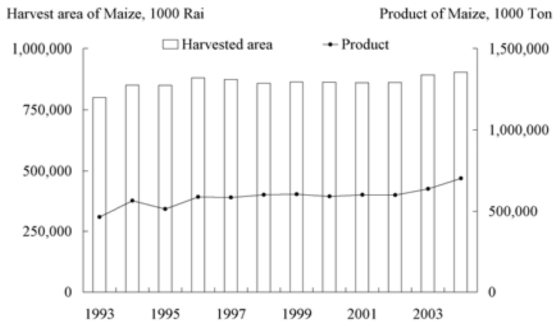
Figure 6.4 shows harvest area and product of main crops in the world. Rice and maize were planted in the high percentage because of food produced to support the population. The fluctuation of plant area in each year depends on the water and climate situations in each region.

In term of product of main crops in the world, the growth rates of each product were gradually increasing. One of interesting points is that the yield of each crop shown in table 6.3. Trend of yield or product per area is increasing in case of the world because of high technology and knowledge used to harvest. At the same time, the yield of each crop in Thailand is lower than the average world value except second rice and cassava.

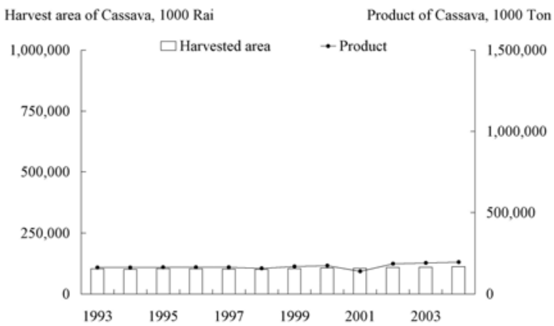
In case of major rice, yield in Thailand is only 60 % of average world yield. There are many reasons are following; type of rice, hydrological and climate factors, irrigation method, etc. However, this gap between Thai yield and the world yield shows possible yield to increase. If the yield in Thailand is higher, farmer can produce more products at the same area and water but gets more benefit. Form this point, high productivity is one of the interesting measures to increase the value of used water in irrigation sector.



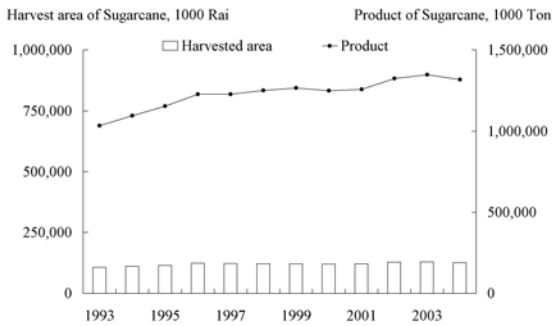
(a.) Rice



(b.) Maize



(c.) Cassava



(d.) Sugarcane

Figure 6.4. Harvest area and product of main crop in the world.

(Source: OAE, FAO.)

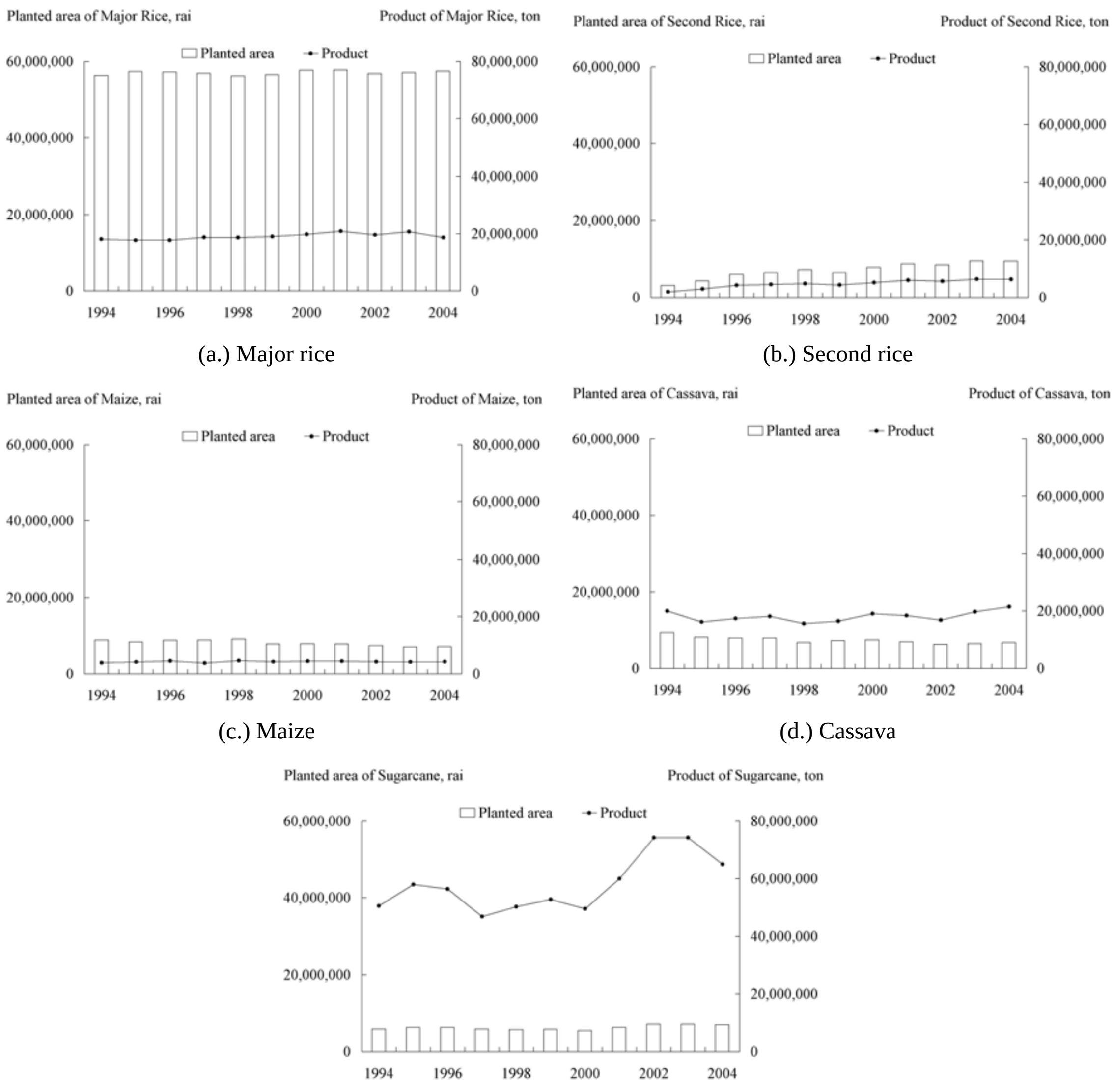
Table 6.3 Yield or product per area of main crop in the world and Thailand.

		1994	1999	2004	Average (1994-2004)
Major rice	World	590	623	636	613
	Thailand	350	348	377	362
	Ratio	0.59	0.56	0.59	0.59
Second rice	World	590	623	636	613
	Thailand	652	681	680	687
	Ratio	1.10	1.09	1.07	1.12
Maize	World	666	701	779	691
	Thailand	469	568	-	505
	Ratio	0.70	0.81	-	0.74
Cassava	World	1,605	1,643	1,760	1,616
	Thailand	2,209	2,479	3,244	2,577
	Ratio	1.38	1.51	1.84	1.60
Sugarcane	World	9,900	10,501	10,463	10,269
	Thailand	8,774	9,010	9,270	9,254
	Ratio	0.89	0.86	0.89	0.90

(Source: OAE, FAO.)

Thailand scale

Figure 6.5 shows main crop area and product in Thailand including; major rice (regular rice was planted in rainy season and use mainly rainfall), second rice (rice was planted in other seasons and mainly located in irrigation service area or close to water source), maize, cassava, and sugarcane. Now the agricultural area in Thailand is gradually decreasing form the past 20 years because of urbanization. However, Royal Irrigation Department (RID) plan to construct more water infrastructure for irrigation service area. From this reason, the planted area of second rice is increasing.



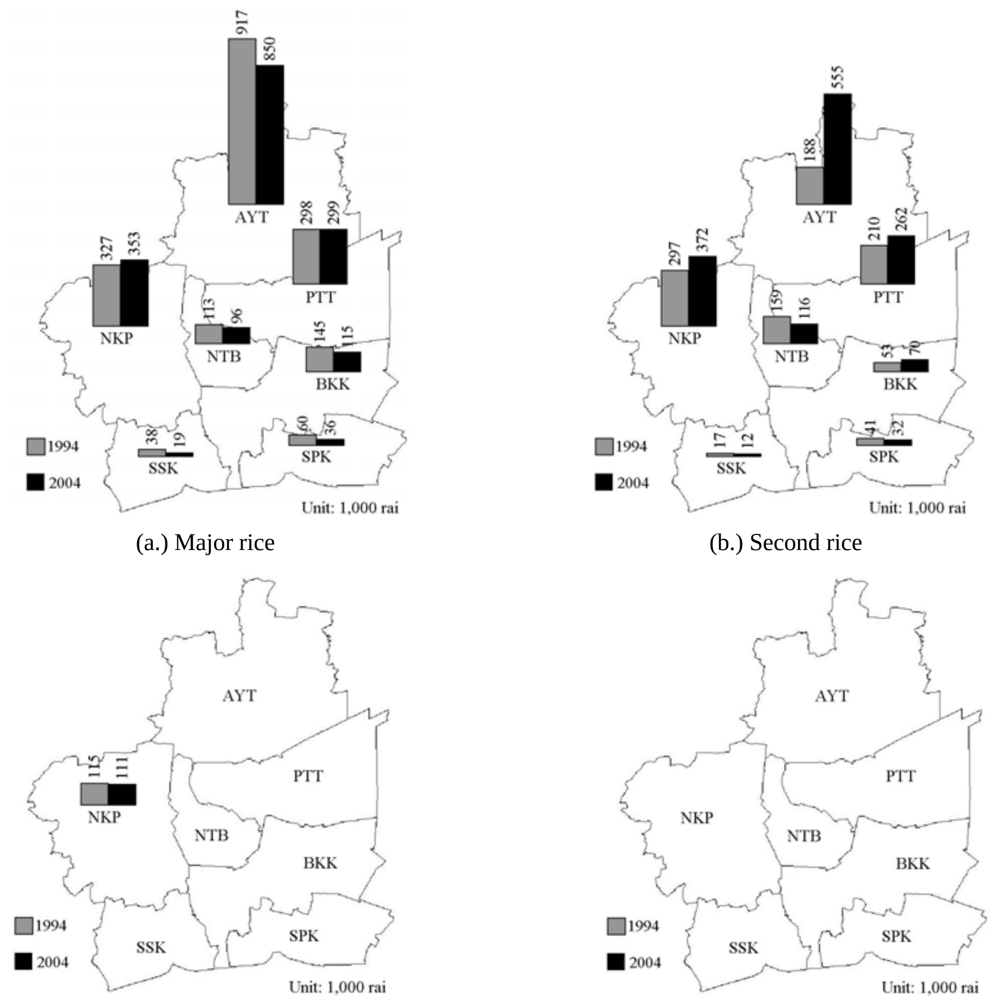
(a.) Major rice (b.) Second rice (c.) Maize (d.) Cassava (e.) Sugarcane

Figure 6.5. Planted area and product of main crop in Thailand.

(Source: OAE.)

Provincial scale

Figure 6.6 shows planted area of each crop in this study area. Rice is the main crop because of soil condition in table 6.4. The main producer in this study area is Ayuttaya province on the upper part. It is interesting that rice farm in the lower part of study is much lower than the upper. The reason is that the main activities in lower part including Bangkok, nontaburi, Samut Prakan, and Samut Sakon are industrial and service area. The land cost in this area was rapidly increasing. The agricultural area was sold and change to industrial and inhabitant use.



(a.) Major rice

(b.) Second rice

(c.) Sugarcane

(d.) Maize and cassava

Figure 6.6. Planted area of main crop in each province.

(Source: OAE.)

In provincial scale, the planted areas in each crop were controlled by the constraints of soil types as shown in table 6.4. The soil type in this study area located in the flat plain of downstream of Chao Phraya River is clay. From this condition, this area is good to plant only rice.

Table 6.4. Physical condition of soil types in each crop and province.

Crop	Province	Physical condition of soil types in agricultural area (rai)				Total area (rai)
		Good	Average	Poor	Total	
Rice	BKK	137,790	168,939	218,822	525,551	931,430
	SPK	79,036	184	382,786	462,006	627,558
	NTB	164,619	37,896	122,450	324,965	388,939
	PTT	182,252	484,109	171,140	837,501	953,660
	AYT	1,015,116	359,517	33,267	1,407,900	1,597,900
	NKP	550,627	162,449	557,720	1,270,795	1,355,204
	SSK	78,730	61,723	242,427	382,880	545,217
Sugarcane	BKK	0	0	525,551	525,551	931,430
	SPK	0	0	462,006	462,006	627,558
	NTB	0	0	324,965	324,965	388,939
	PTT	0	0	837,465	837,501	953,660
	AYT	0	833	1,407,067	1,407,900	1,597,900
	NKP	190,631	57,628	1,022,536	1,270,795	1,355,204
	SSK	0	0	382,880	382,880	545,217
Maize	BKK	0	0	525,551	525,551	931,430
	SPK	0	0	462,006	462,006	627,558
	NTB	0	0	324,965	324,965	388,939
	PTT	0	2,192	835,309	837,501	953,660
	AYT	0	133	1,407,766	1,407,900	1,597,900
	NKP	0	0	1,270,795	1,270,795	1,355,204
	SSK	0	0	382,880	382,880	545,217
Cassava	BKK	0	0	525,551	525,551	931,430
	SPK	0	0	462,006	462,006	627,558
	NTB	0	0	324,965	324,965	388,939
	PTT	0	40	837,426	837,501	953,660
	AYT	0	0	1,407,900	1,407,900	1,597,900
	NKP	0	0	1,270,795	1,270,795	1,355,204
	SSK	0	0	382,881	382,880	545,217

(Source: LDD)

Water use unit analysis

Crop water demand is usually measured in terms of evapotranspiration (M. Karamouz, 2003). This rate depends on climate factors such as temperature, radiation, wind speed, precipitations, soil moisture, surface properties and etc. crop water requirement are estimated on reference crop evapotranspiration or ET_0. ET_0 is the maximum evapotranspiration rate that the atmosphere is capable of extracting from a well-watered field. Methods of estimating ET_0 depends on conditions and constraints in each area. The water requirement in each crop can be estimated as follows:

$$ET_{crop} = K_c * ET_0 \quad \text{(6.2)}$$

Where,

- ET_{crop} is the water requirement in each crop
- K_c is crop coefficient
- ET_0 is the maximum evapotranspiration

Royal Irrigation Department (RID) collected related data and calculated the water requirement as shown in table 6.5 by using modified Penman-Monteith method recommended to be suitable with climate and hydrological factors of Thailand.

Table 6.5. Water requirement in each crop in study area.

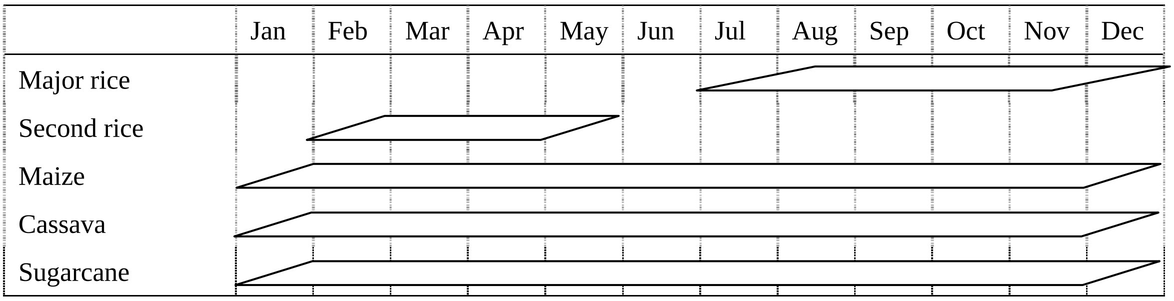
Possible crop in study area	ET_{crop} , water requirement in each crop; mm.
Major rice	1155
Second rice	1155
Sugarcane	1632

(Source: RID)

From equation 6.1, water use unit per crop area is shown in term of (ET_{crop} - P_e). P_e or effective rainfall is excess rainfall or precipitation that is converted to runoff. However, effective rainfall in each crop depends on crop pattern shown in table 6.6. Major rice was planted from the starting of rainy season or July and harvested in the end of December but the second rice was planted from February to May. Farm crops can be plant in the whole year.

Finally water use unit per crop area was calculated by using data of water requirement in each crop and effective rainfall in table 6.5 to 6.8. However, irrigation sector is an activity that highly depended on rainfall factor. From this topic, uncertainty in rainfall in the future was considered as rainfall scenarios in table 6.9. Table 6.9 was analyzed from rainfall data in the past and made the order from the lowest to the highest value to find the rainfall depth in each return period. In this scenario, return period at 2 year was defined as low rainfall year. The 1.25 and 5 years of return periods are normal and high rainfall year by order.

Table 6.6. Crop pattern in each main crop.



(Source: RID)

Table 6.7. Effective rainfall of rice in each province.

Unit: mm.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
BKK	9	30	29	65	215	149	155	197	289	231	48	10	1426
SPK	10	24	21	59	166	132	131	166	261	201	44	8	1223
NTB	6	17	20	53	140	131	147	170	252	189	46	8	1178
PTT	6	17	21	66	148	157	179	201	270	191	42	8	1304
AYT	6	15	22	58	148	147	160	165	254	170	37	7	1188
NKP	3	9	15	45	123	119	126	139	234	205	52	6	1077
SSK	5	18	18	47	142	122	135	149	233	216	74	10	1171

(Source: RID)

Table 6.8. Effective rainfall of farm crops in each province.

Unit: mm.

	Jan	Feb	Mar	Apr	Total	Avg.	Jul	Aug	Sep	Oct	Total	Avg.
BKK	-	-	-	-	-	-	-	-	-	-	-	-
SPK	-	-	-	-	-	-	-	-	-	-	-	-
NTB	5.9	12.7	14.1	35.1	67.8	17	82.3	116	133.6	76.7	408.6	102.2
PTT	5.5	13.6	16.6	42.2	77.9	19.5	82.3	132	133.6	76.7	424.6	106.2
AYT	5.6	12	16.4	36.6	70.6	17.7	80.5	108.9	130.7	75	395.1	98.8
NKP	3	8.9	12	29.1	53	13.3	74.1	92.7	127.7	73.3	367.8	92
SSK	-	-	-	-	-	-	-	-	-	-	-	-

(Source: RID)

Table 6.9. Rainfall data and rainfall scenario.

Raw data		Sorted data		Probability	Return period	Scenario
Year	Rainfall, mm.	Order	Rainfall, mm.		RT, Yr.	
1994	1,716	1	1,308	0.08	12.00	Low rainfall year
1995	1,639	2	1,384	0.17	6.00	RT = 5 yr,
1996	1,681	3	1,404	0.25	4.00	RF = 1,392 mm.
1997	1,404	4	1,449	0.33	3.00	
1998	1,449	5	1,548	0.42	2.40	Medium rainfall year
1999	1,780	6	1,639	0.50	2.00	RT = 2 yr,
2000	1,791	7	1,680	0.58	1.71	RF = 1,639 mm.
2001	1,680	8	1,681	0.67	1.50	
2002	1,548	9	1,716	0.75	1.33	High rainfall year
2003	1,384	10	1,780	0.83	1.20	RT = 1.25 yr,
2004	1,308	11	1,791	0.92	1.09	RF = 1,756 mm.

(Source: Thai Meteorological Department)

Irrigation water demand

Finally, irrigation water demand was calculated from summation of water in each crop as shown in equation 6.3.

$$WD_{irri} = \sum_{crop=1}^{n} (ET_{crop} - Pe_{crop}) * A_{crop} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.3)$$

Where,

WD_{irri} is irrigation water demand

ET_{crop} is the water requirement in each crop

$P_{e,crop}$ is effective rainfall

A_{crop} is the crop area

Crop is possible crop in study area; major rice, second rice, and sugarcane

6.2.2 Livestock water demand model

Livestock water demand can be estimated by using the following equation:

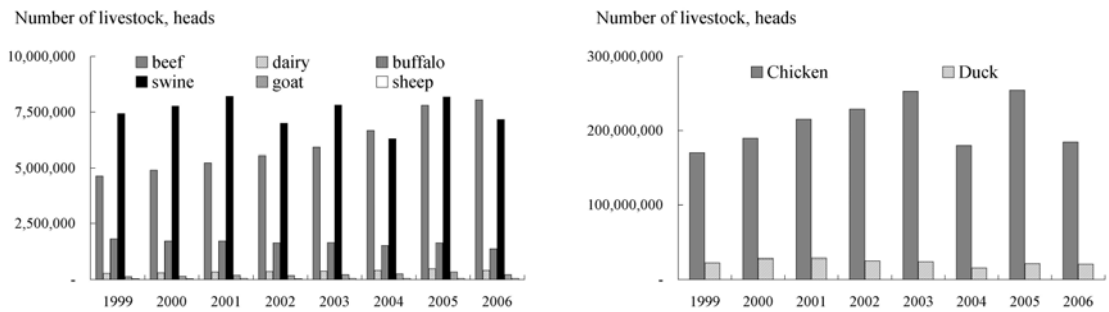
$$WD_{live} = No_{live} * WU_{live} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.4)$$

Where,

WD_{live}	is livestock water demand
No_{live}	is number of each livestock
WU_{live}	is water use unit per head of each livestock
live	consists of beef, dairy, buffalo, swine, goat, sheep, chicken, and duck

Thailand scale

Main livestock in Thailand consists of beef, dairy, buffalo, swine, goat, and sheep, chicken, and duck shown in figure 6.7. The rapid increasing in number of chicken in year 2004 is effects of protection strategy to protect Bird Flu. Trend of livestock except buffalo is gradually increasing from year 1999 because of higher demand of food.



(a.) beef, dairy, buffalo, swine, goat, and sheep

(b.) chicken, duck

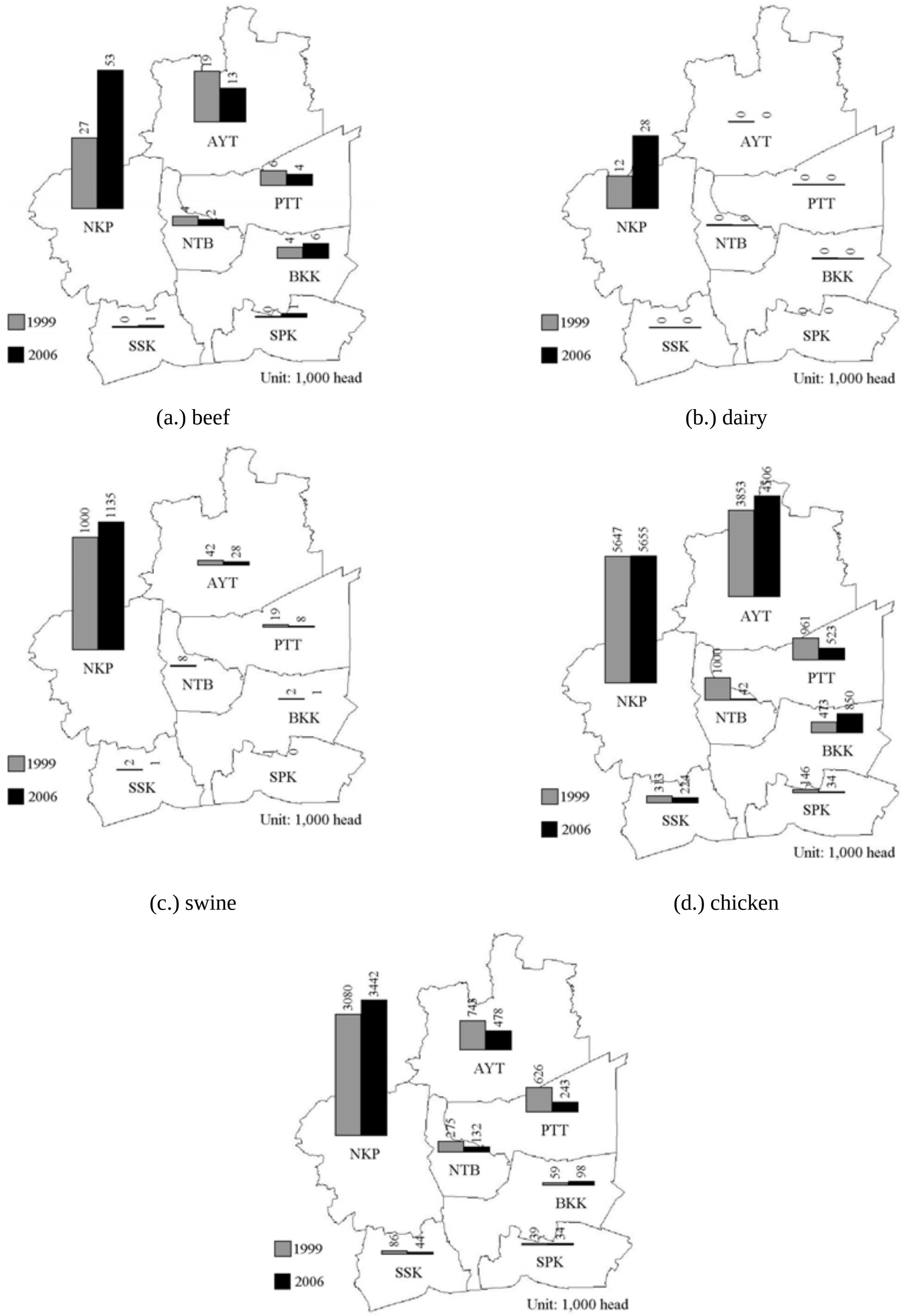
Figure 6.7. Number of livestock in study area.

Provincial scale

Figure 6.8 shows number of livestock in provincial scale. Study area can be divided into 2 groups as following; (1) high amount of livestock or main producer in this sector including Nakon Pathom (NKP) and Ayutthaya (AYT), and (2) low amount of livestock such as PTT, NTB, BKK, SSK, and SPK. Numbers of each livestock in each province were forecasted by using trend analysis for the data of the past.

Water use unit analysis

Water use unit per head of each type of livestock was collected and presented by Department of Livestock Development (DLD) as following; (1) group of "beef, dairy, buffalo, swine, goat, and sheep" needs 40 liter per head per day, (2) chicken need 1 liter per head per day, and (3) duck need 3 liter per head per day.



(a.) beef (b.) dairy

(c.) swine (d.) chicken

(e.) duck

Figure 6.8. Number of livestock in provincial scale.

(source: DLD)

Livestock water demand

Finally, Livestock water demand was calculated from summation of water in each type of livestock as shown in equation 6.5.

$$WD_{live} = \sum_{live=1}^{n} No_{live} * WU_{live} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.5)$$

Where,

No_{live} is number of each livestock

WU_{live} is water use unit per head of each livestock

live consists of beef, dairy, buffalo, swine, goat, sheep, chicken, and duck

6.2.3 Model formulation

From the previous topics, two models (irrigation and livestock water demand model) were developed as agricultural water demand management model by using GAMs language.

This model was designed to run with the same order as schematic diagram shown in Figure 6.9 as follow;

1. Irrigation model
   Step 1: input data for Thailand scale
   Step 2: predict parameter by trend analysis and form input-output table
   Step 3: crop area prediction model of Thailand scale
   Step 4: input data for provincial scale
   Step 5: crop area prediction model of provincial scale
      Checking with constraints of
      - physical condition of soil types
      - condition of total agricultural area
      - condition of inside/outside irrigation service of RID
      Calculation
      - harvested area, yield, product, and value
   Step 6: irrigation water demand in provincial scale
2. Livestock model
   Step 1: input data for Thailand scale
   Step 2: livestock prediction model
   Step 3: livestock water demand model
3. Agricultural model
   Summation of irrigation and livestock sector.

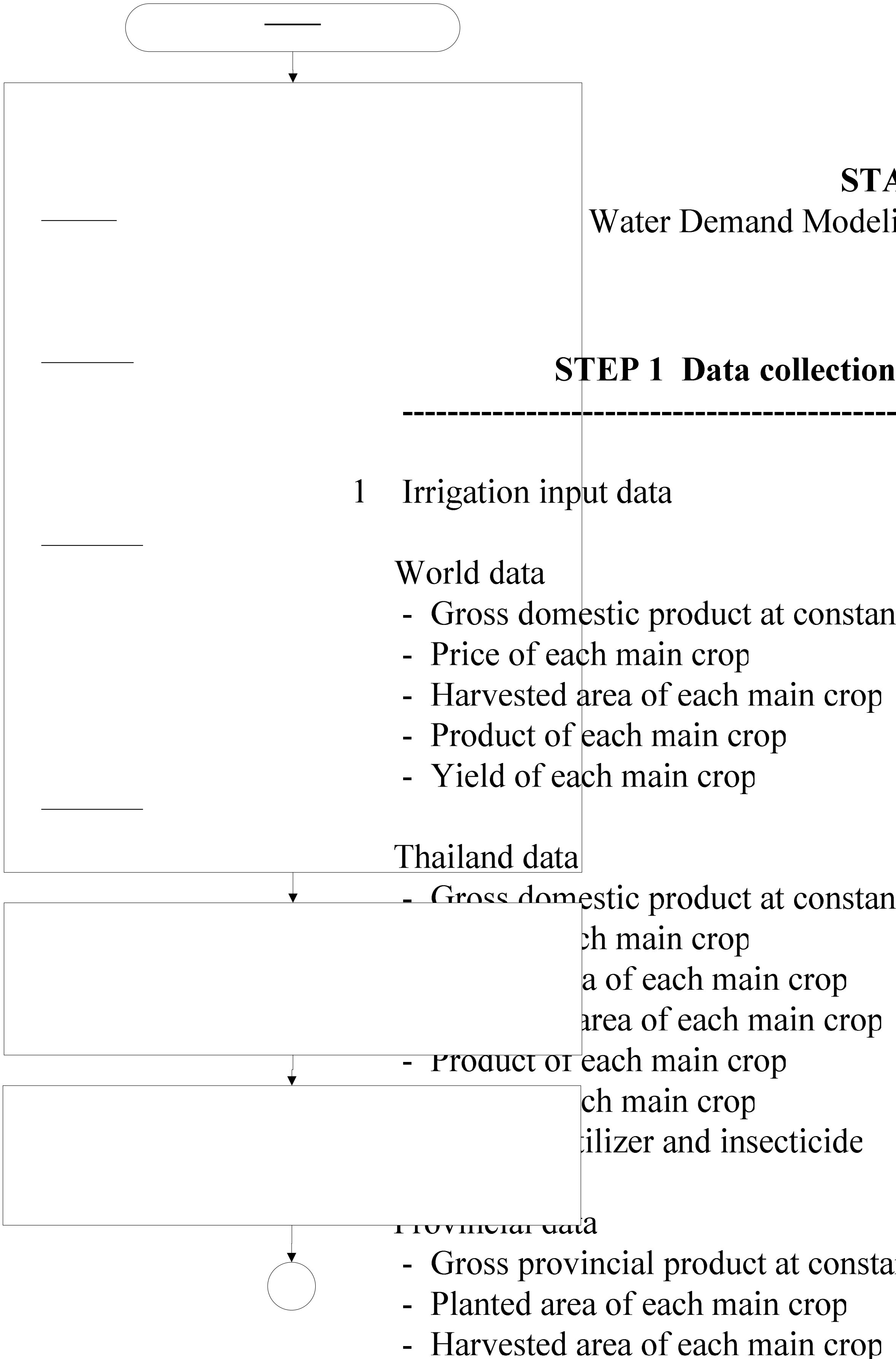


Figure 6.9. Schematic diagram of agricultural water demand management model.

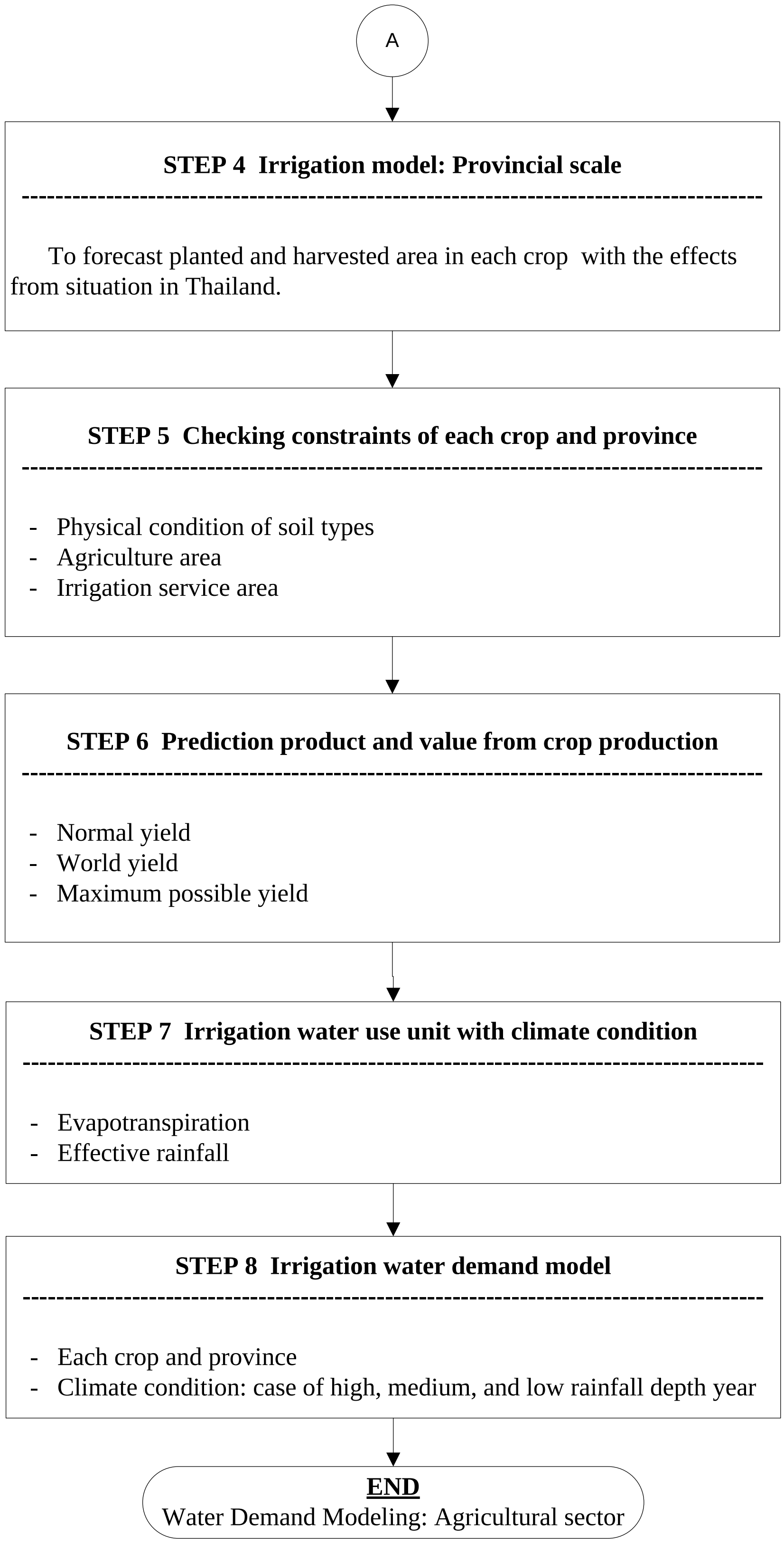


Figure 6.9. Schematic diagram of agricultural water demand management model. (Cont'd)

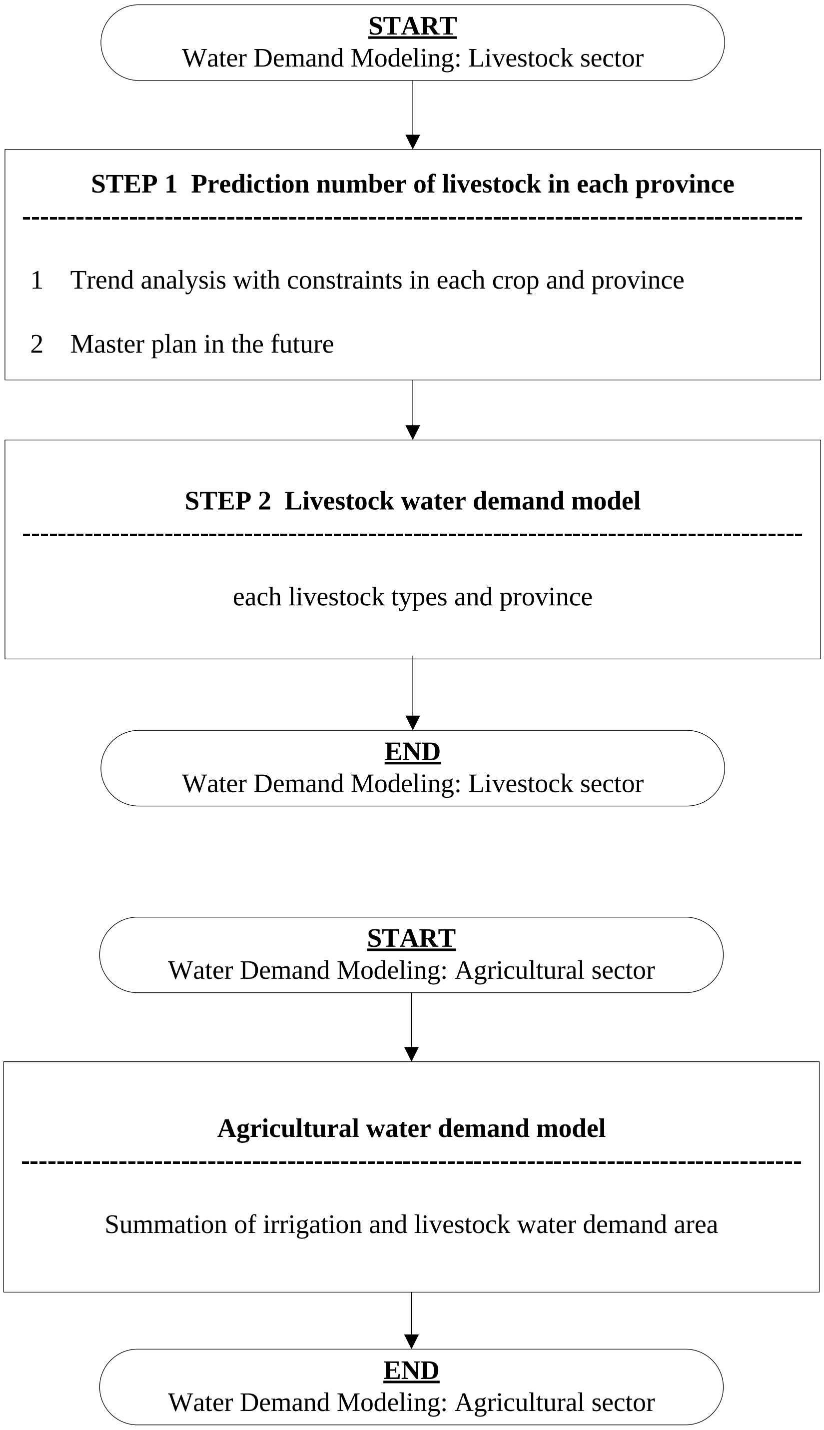


Figure 6.9. Schematic diagram of agricultural water demand management model. (Cont'd)

6.3 Agricultural Water Demand Management Model & Results

6.3.1 Irrigation water demand model

Thailand scale

Thailand crop area model was developed in national scale with dimension of time series or matrix of 5 X 20 (5 major crop with 20 years) in forecasting step. The crop area model was developed by using techniques of time series and cross section pooling. The method is pooled least square in case of fixed effect with no weighting by White Heteroskedasticity-Consistent Standard Errors & Covariance. The equation of model was shown in equation 6.5 and coefficient of model in Table 6.10.

A_TH(crop,t) = C1(crop) * GDP_AGR_WR(t)
+ C2(crop) * GDP_AGR_TH(t)
+ C3(crop) * CO_Fe(t-1)
+ C4(crop) * CO_In(t-1)
+ C5(crop) * PR_WR(crop,t-1)
+ C6(crop) * PR_TH(crop,t-1)…..……………………….....(6.5)

Where,

A_TH(crop,t)	is Thailand crop area in each crop and forecasting year
C (prov)	is constant in each crop
GDP_AGR_WR(t)	is world gross domestic product in agricultural sector
GDP_AGR_TH(t)	is Thailand gross domestic product in agricultural sector
CO_Fe(t-1)	is cost of fertilizers in last year
CO_In(t-1)	is cost of insecticides in last year
PR_WR(crop,t-1)	is world unit price of each crop in last year
PR_TH(crop,t-1)	is Thailand unit price of each crop in last year
crop	consists of major rice, second rice, maize, cassava, and sugarcane

Figure 6.10 shows planted area of main crop forecasted in Thailand scale. The results can be divided into two groups;

(1) Decreasing crop area: major rice, maize, and cassava

This situation is as same as the present trend. The irrigation area is decreasing because of urbanization in Thailand. The irrigation area was changed to industrial and inhabitant area especially in Bangkok and vicinities.

(2) Increasing crop area: second rice and sugarcane

This increasing crop area is second rice because the expansion of irrigation service area. Farmers can use same area to plant rice by twice a year with supported water from irrigation system. In case of sugarcane, there is more demand from international with higher price of sugarcane.

Table 6.10. Variable coefficients and statistic analysis of Thailand crop area model

Variable		Statistic analysis	
		Coefficient	Std. Error
1. GDP_AGR_WR	- major rice	8.485582	7.128836
	- other crop	….	….
2. GDP_AGR_WR	- major rice	89.28040	29.17605
	- other crop	….	….
3. CO_Fe	- major rice	-208.4669	54.98420
	- other crop	….	….
4. CO_In	- major rice	87.88853	6.833427
	- other crop	….	….
5. PR_WR	- major rice	62730.37	6949.777
	- other crop	….	….
6. PR_TH	- major rice	-3330.011	567.1943
	- other crop	….	….
R-squared	0.78	Durbin-Watson stat	1.618784

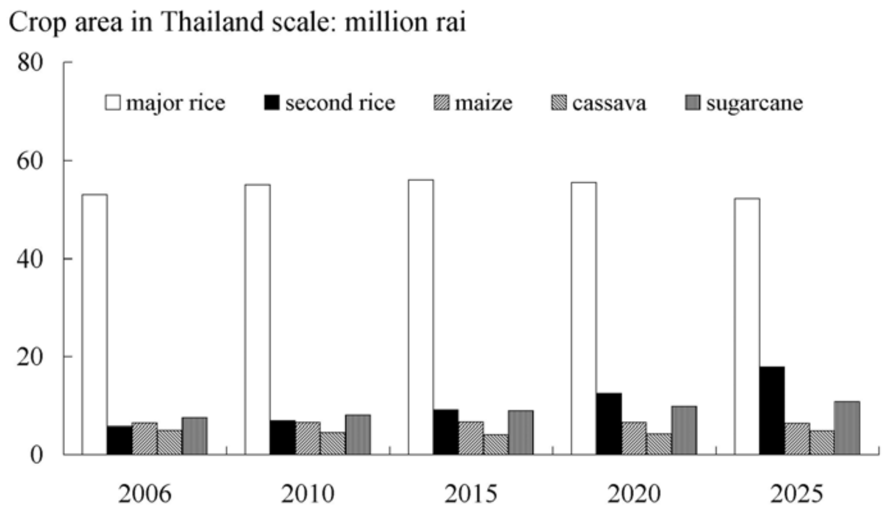


Figure 6.10. Planted area of main crop in national scale.

The results of sensitivity analysis of Thailand crop area model was shown in table 6.11. The main parameters are Thailand Agri GDP, Cost of insecticides and Thailand crop unit price with high percentage of change from changed variables.

Table 6.11. Sensitivity analysis of Thailand crop area model.

Variables	Δ% Var	Major rice	Second rice	Maize	Cassava	Sugarcane
World Agri GDP	10	0.1	4.3	2.0	19.7	10.3
	20	0.1	8.6	4.1	39.4	20.6
Thailand Agri GDP	10	2.6	3.1	5.1	24.5	15.3
	20	5.2	6.3	10.3	49.0	30.5
Cost of fertilizers	10	0.2	0.1	0.2	1.2	0.1
	20	0.4	0.2	0.4	2.4	0.1
Cost of insecticides	10	3.4	4.2	3.3	6.7	0.5
	20	6.8	8.4	6.6	13.4	1.0
World unit price	10	1.7	1.1	3.1	0.6	2.1
	20	3.4	2.3	6.3	1.2	4.2
Thailand unit price	10	5.4	5.8	2.8	3.3	2.5
	20	10.9	11.7	5.7	6.7	5.0

Provincial scale

Provincial crop area model was developed with dimension of time series or matrix of 7 X 20 (7 provinces with 20 years) in forecasting step. The analyzed method is as same as Thailand crop area model but in this step constraints and condition in each province were considered. The equation of model was shown in equation 6.6 and coefficient of model in Table 6.12.

A_PR(crop,prov,t) = C1(prov) * A_TH(crop,t)
+ C2(crop) * GDP_AGR_PR(prov,t)/GDP_AGR_TH(t)..(6.6)

Where,

A_PR(crop,prov,t)	is provincial crop area in each forecasting year
A_TH(crop,t)	is Thailand crop area in each crop and forecasting year
C (prov)	is constant in each crop
GDP_AGR_PR(t)	is gross provincial product in agricultural sector
GDP_AGR_TH(t)	is Thailand gross domestic product in agricultural sector
crop	consists of major rice, second rice, maize, cassava, and sugarcane

prov consists of 7 provinces in study area.

Constraint:
- Soil condition of each crop and province
- Possible agricultural area
- Inside and outside irrigation service area of RID

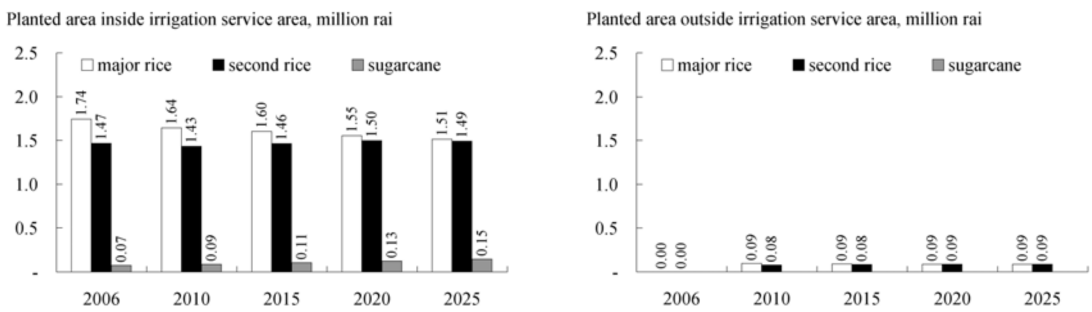
Table 6.12. Variable coefficients and statistic analysis of provincial crop area model

Variable		Statistic analysis	
		Coefficient	Std. Error
1. A_TH	- BKK	0.001438	0.002615
	- other provinces	….	….
2. GDP_AGR_PR/GDP_AGR_TH	- BKK	9187920.	40758331
	- other provinces	….	….
R-squared	0.69	Durbin-Watson stat	1.500010

Figure 6.11 and 6.12 show provincial planted area of main crop forecasted inside and outside irrigation service area. The results can be divided into two groups;

(1) Case of inside irrigation service area

In this case, high percentage of crop area is major rice and second rice because of physical soil condition of clay. Only sugarcane was planted in Nakon Pathom. The ratio of major and second rice is equal because of completed irrigation service area in these 7 provinces. However, the irrigation area of major rice is decreasing because of urbanization but crop area of second rice is increasing to as same level as major rice because of completed irrigation service area.



(a.) Inside irrigation service area

(b.) Outside irrigation service area

Figure 6.11. Planted area of main crop inside and outside irrigation service area.

(2) Case of outside irrigation service area

The lower part of study area is mainly industrial and inhabitant area. Form this reason; there is no development of irrigation project. In the upper part of 7 provinces, there are many rice fields mainly in Ayuttaya province. Many irrigation projects are located in this area and most of them are already completed. Without new development plan, it can be said that there is no more irrigation service area in this area. Figure 6.11 shows constant of crop area outside irrigation service area.

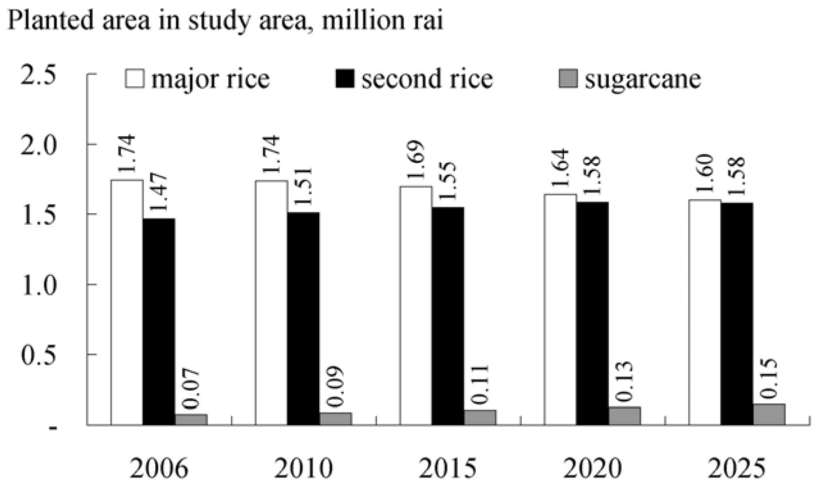


Figure 6.12. Planted area of main crop in study area.

The result of sensitivity analysis of provincial crop area model was shown in table 6.13. The main parameters depend on conditions in each province.

Table 6.13. Sensitivity analysis of provincial crop area model.

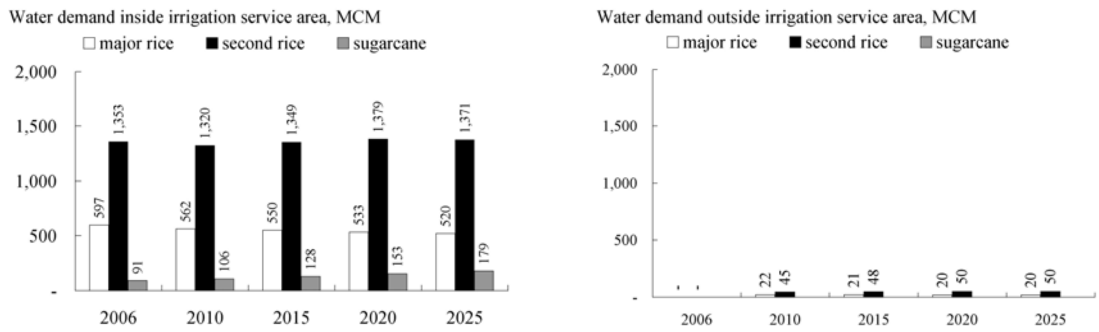
Variables	Δ% Var	BKK	SPK	NTB	PTT	AYT	NKP	SSK
Thai crop area	10	7.2	18.0	2.5	1.2	7.3	6.6	16.2
	20	14.3	36.1	4.9	2.4	14.7	13.3	32.5
Ratio of Agri GPP	10	2.8	8.0	7.5	10.2	1.0	1.0	6.2
and Thai Agri GDP	20	5.7	16.1	15.1	20.3	1.9	2.1	12.5

Water use unit analysis

Water use unit per crop area in each crop was analyzed with evapotranspiration and effective rainfall shown in equation 6.1-6.3. Finally, rainfall scenarios in table 6.9 were applied to forecast irrigation water demand in each possibility of rainfall year.

Irrigation water demand

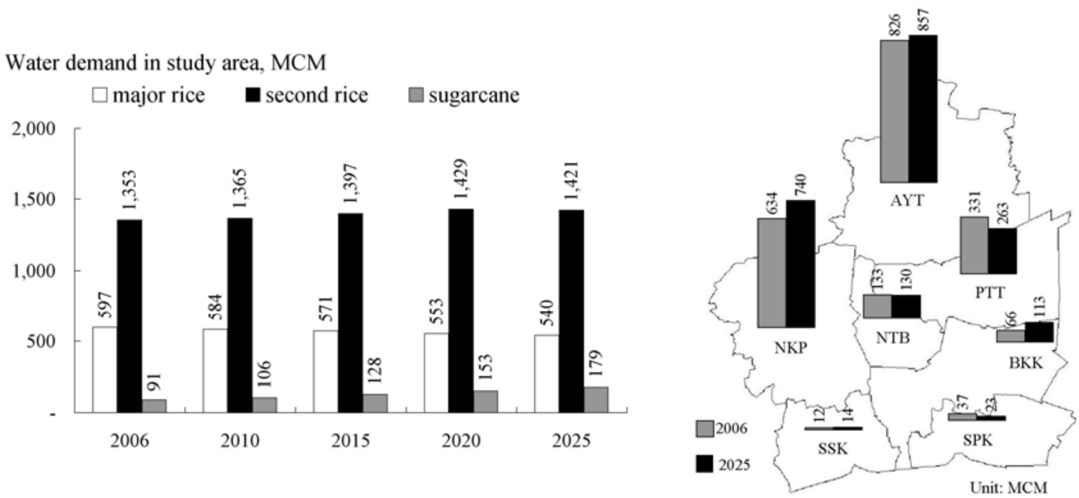
Figure 6.13 and 6.14 show Irrigation water demand of main crop inside and outside irrigation area in case of normal rainfall year. Actually, water requirement of second rice is as same as major rice but major rice was planted in rainy season with high effective rainfall. Form this reason; water demand for major rice is less than case of second rice. The main water consumer in this area is second rice approximately 65 % of total.



(a.) Inside irrigation service area

(b.) Outside irrigation service area

Figure 6.13. Irrigation water demand of main crop inside and outside irrigation area in case of normal rainfall year.

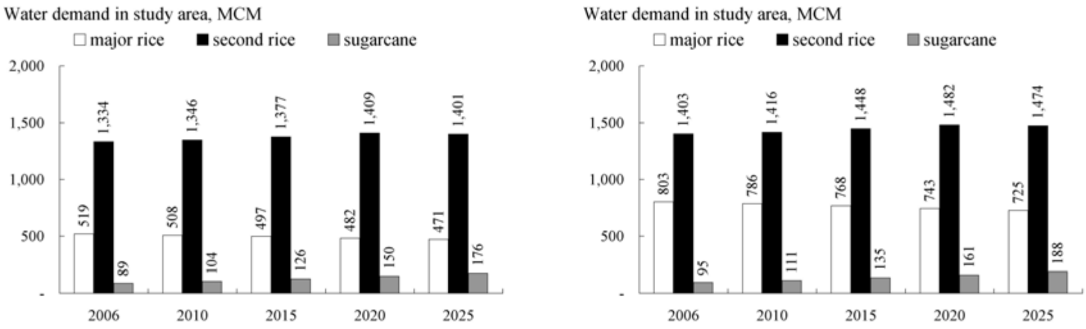


(a.) Total irrigation water demand

(b.) Provincial scale

Figure 6.14. Irrigation water demand of main crop in study area in case of normal rainfall year.

Figure 6.15 show irrigation water demand in high and low rainfall scenarios. Water demand in low rainfall year is the maximum because of lowest effective rainfall.



(a.) high rainfall year (b.) low rainfall year

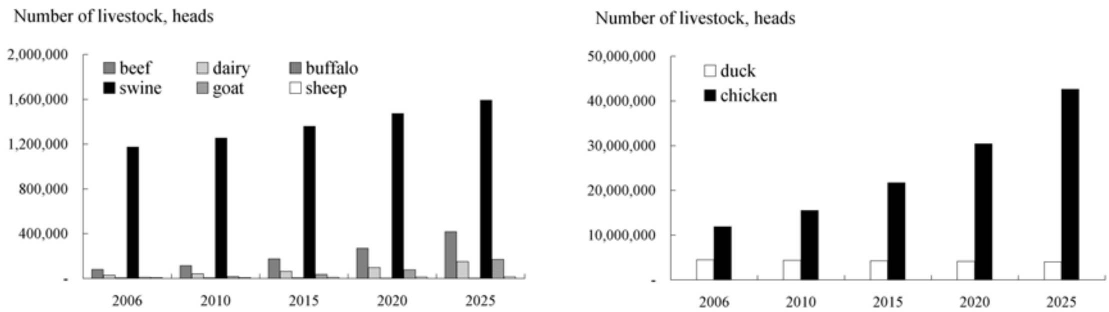
Figure 6.15. Irrigation water demand of main crop in case of high and low rainfall year.

6.3.2 Livestock water demand model

Figure 6.16 shows forecasted number of livestock in study area. There are two main group as following; (1) increasing number of livestock consists of beef, dairy, swine, goat, sheep, and chicken.; (2) decreasing number of livestock as buffalo and duck.

Livestock water demand

Livestock water demand was calculated and shown in figure 6.17. The main water consumers are swine and chicken concentrated in Nakon Pathom approximately 75 %.



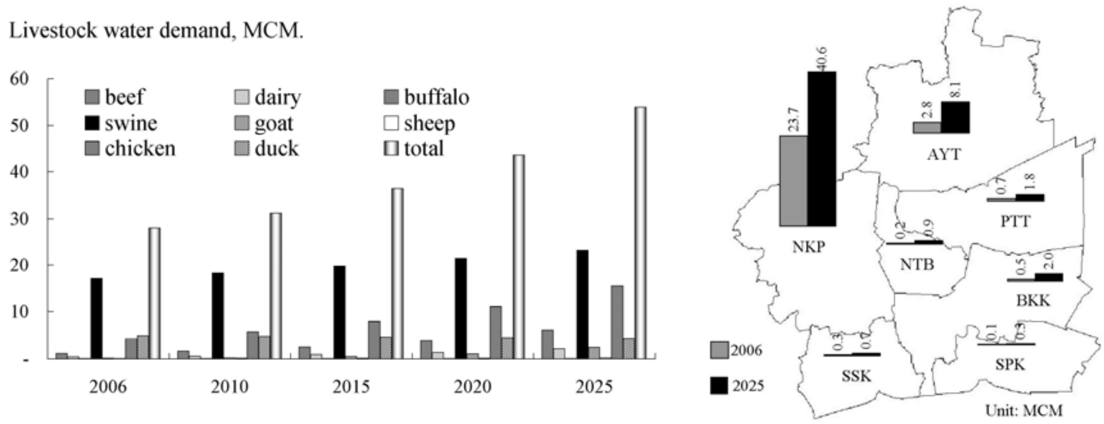
(a.) beef, dairy, buffalo, swine, goat, and sheep (b.) chicken, duck

Figure 6.16. Number of livestock in study area.

6.3.3 Agricultural water demand model

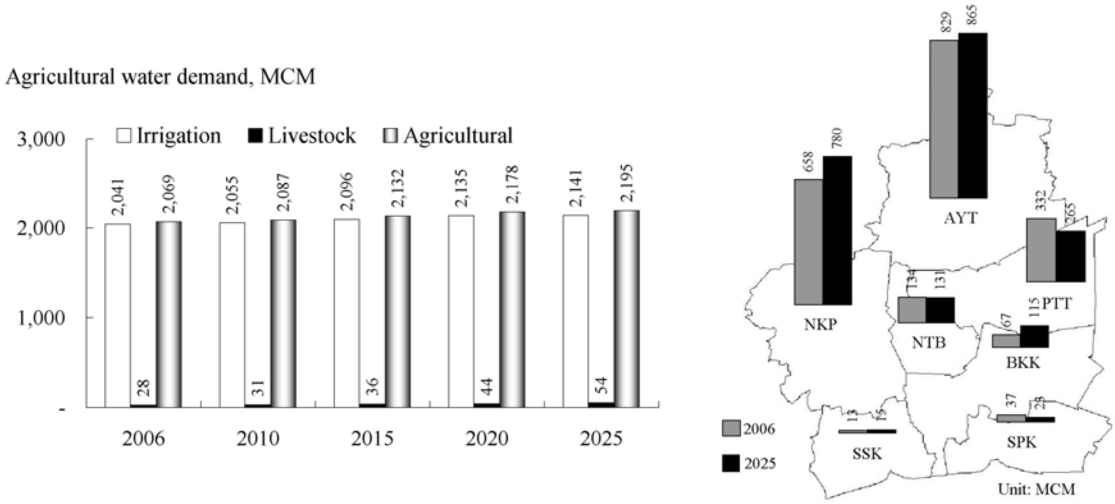
Agricultural water demand is summation of irrigation and livestock water demand. Figure 6.18 shows agricultural water demand in normal rainfall year. In agricultural topic, irrigation water is the main water consumer approximately 97 % of total demand.

The upper part of study area is high water user in agricultural sector because of irrigation society.



(a.) Total irrigation water demand (b.) Provincial scale

Figure 6.17. Livestock water demand in study area.



(a.) Total agricultural water demand (b.) Provincial scale

Figure 6.18. Agricultural water demand in study area.

6.4 Summary

Proposed agricultural water demand model can forecasted water demand in irrigation and livestock sectors. Irrigation water demand model is function of crop area and water use unit per area in each crop. National crop area model was firstly analyzed with situations of world and Thailand market such as GDP in agricultural sector, cost of insecticides & fertilizers, and unit price of agricultural product. Provincial irrigation water demand was calculated by using function of Thailand crop area and ratio of GPP and GDP. Water use unit was calculated by evaportranspiration and effective rainfall with scenario of high, normal, and low rainfall year. Livestock water demand was predicted by using trend analysis. In this study area, irrigation is main sector that need high percentage of water.

However, the next interesting topic is how to manage the water share of each user and activity with the changing economics structure from declared policy?

Chapter 7

Conclusions and Recommendations

Providing water for rapidly increasing of population, urbanization, and developing economics activities in agricultural, industrial, and service sector is increasingly difficult for many cities around the world. Lower Chao Phraya River Basin including Bangkok (the capital of Thailand), and Vicinities is one of the important area faced the difficulties in development of economic activities such as industrial and service sector with constraint of groundwater under groundwater ban law.

Changing economic activities resulted from declared strategy and target growth rate from governmental side such as industrial master plan and free trade agreement will affect not only industrial part, but also in service sector with migrations from job opportunity and income differential, and agricultural with higher demand of crop product for raw material in food industrial type.

Not only economic activities were changed, but water demand was changed also because an increase in demand of output resulted from declared policies is likely to cause a rise in need of infrastructure especially water. The higher demand in the future which is needed to produce the target growth of gross domestic product or GDP is motivated force for all level of related governmental agencies.

There are two main water management system; water supply and demand schemes. The predominant approach for the past is generally water supply schemes; however, developing new water sources is more difficult because of limited water supply, conflict with environmental viewpoint, and higher cost of water per cubic meter. It is almost certain that water demand management is increasing powerful with ideas of improving efficiency and sustainable use of water with considering economic, social and environment. From this reason, the model developed in this research was mainly concentrated in water demand management model.

This water demand management model and source codes were developed by using GAMs language with topics of industrial, household, and agricultural sectors under economics viewpoint with physical constraints in each province. Firstly, Input-output table model was developed to analyze changing economic structure by using economic scenarios of national and international scale in each sector such as; more production in industrial part, effects to population structure with migration from job opportunity and income differential, and need of agricultural raw material for food factory. Secondly, water use unit in each sector was calculated by using secondary data from Thai government agencies and questionnaires for industrial and domestic sector. After previous step, water demand in each sector was forecasted under economic scenarios. Water supply was analyzed under constraints of each water source affected from future master plan, laws, regulations, and climate.

For non-agricultural sector, governmental option scenarios with equilibrium analysis, water demand-supply curve, and pricing policy were applied to calculate the impacts to Thai economic structure or target. Policy makers can use the result from this step to make decision with declared strategy policy under limitation of water in form of GDP or monetary term. Next, strategic decision making was applied for non-agricultural sector for considering whether and how to invest the water infrastructure under uncertainty of water demand growth rate in the future. Finally, integrated water demand model was developed to manage water and benefit sharing analysis.

7.1 Industrial sector

Normal growth rate is the main reason to increase industrial water demand approximately 2.56 times from year 2005. The reason is that the industrial GDP growth rate used in this model is high approximately 8.2 % analyzed from data of the last 20 year (high growing period of industrial sector). However, Policy makers can edit the GDP growth rate again when they design the new target growth of industrial sector. Industrial master plan declared by governmental agency is the next main strategy to increase industrial water demand approximately 31.5 % of case of normal growth rate in year 2025. Impact from free trade agreements with global and group of the United States, Japan, and China is only 2.3 and 5.2 % increased from case 2. The higher water demand from declared strategy shows the water used in each economic activity to produce the target of growth rate of Gross Domestic Product (GDP). Table 7.1 shows the higher demand in the future in all case.

However, there are question is whether the declared strategy is suitable with the constraints in Lower Chao Phraya River Basin. The study area was declared as critical groundwater zone. It means that factory located in service area of pipe water cannot use groundwater. Unfortunately, food and textiles factories are mainly located in this area. These industrial types needs groundwater because of chlorine in pipe water will react with chemical substance in production process but food and textiles are the main target of industrial master plan. This will be conflicts between declared strategy and constraints of water in this study area. However, policy makers have governmental options, with/without new water infrastructure and subsidy or paid by water users, to manage industrial water and have to plan for the next 5, 10, or 20 years.

Table 7.1 Industrial water demand.

Economic scenarios	Industrial water demand, MCM				
	2006	2010	2015	2020	2025
1. Normal growth rate	712	881	1,140	1,456	1,824
2. Normal Gr with Ind master plan	738	958	1,318	1,792	2,398
3. Normal Gr. with Ind master plan and FTA with Global.	753	978	1,347	1,833	2,453
4. Normal Gr. with Ind master plan and FTA with USA, China, and Japan.	773	1,004	1,384	1,884	2,523

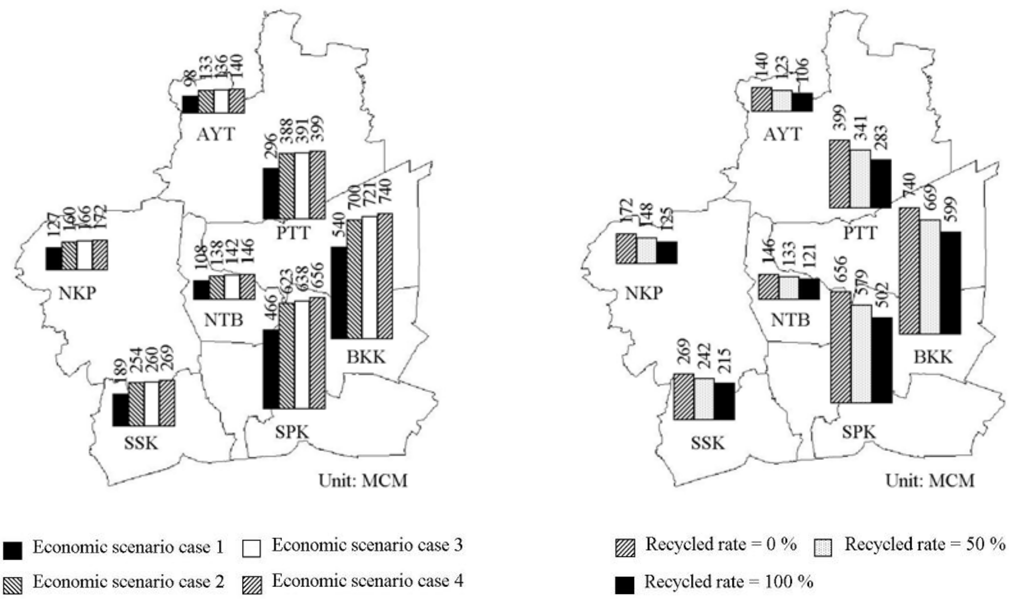
The effects of declared policy were shown in table 7.2. In case of 0 % recycled water, although water infrastructure was constructed by master plan of Metropolitan Waterworks Authority with subsidy, it is still having water shortage. The GDP of this case is only 0.03 % from the target of GDP of declared strategy is 9.7 %. The reason is no water to use in production line. In case of 50 % recycled water, the water situation is better but it is still having water shortage problem. The maximum GDP in this case is approximately 2.42 %. In case of 100 % recycled water, there is no water shortage in case of new water structure with subsidy. It means that water for industrial sector is enough to produce the target of GDP. The produced GDP is approximately 9.55 %.

Table 7.2 Effects from recycled water under governmental option scenarios in year 2025.

			Case 1	Case 2	Case 3	Case 4
			Sub-Inf	Sub-NoInf	NoSub-Inf	NoSub-NoInf
Subsidy from governmental side			With	With	Without	Without
New water infrastructure			With	Without	With	Without
Ratio of recycled water with Japan case						
- 0 %	GDP growth rate,	%	0.055	0.003	0.003	0.003
	Water shortage,	MCM/d.	2.047	2.527	-	-
- 50 %	GDP growth rate,	%	2.418	0.589	0.003	0.003
	Water shortage,	MCM/d.	0.864	1.344	-	-
- 100 %	GDP growth rate,	%	9.547	7.561	0.003	0.003
	Water shortage,	MCM/d.	**-0.320**	0.160	-	-

This analysis is based on evaluation standard concentrated in maximum net benefit. In the practical, policy makers can make decision depending on their objectives such as to spare water from the recycled process, minimum cost with acceptable target of GDP, and etc.

Figure 7.1 shows industrial water demand in each province. Bangkok (BKK), Samut Prakarn (SPK), Pathum Thani (PTT), and Samut Sakorn (SSK) are the main water consumers in industrial sector. These four provinces are the downstream of Chao Phraya and Tha Chin River whose water quality needs high level of treatment before using. It is certain that water users have limitations of water sources from groundwater ban law and quality of water in the rivers. Recycled water is one of interesting measures for providing new water supply without new water source.



(a) Classified by economic scenarios (b) Classified by recycled rates

Figure 7.1 Industrial water demand in each economic scenario and recycled rate in year 2025.

7.2 Household sector

Thailand population in year 2025 will be 72.8 million peoples from 62.8 million peoples in year 2006. In study area, 10.6 million peoples in year 2006 will increase to 11.5 million peoples or more 0.9 million peoples in next 20 years. The number of population is not the main effects to change household water demand rapidly but changed water use unit from economic and society will play an important role in changing water demand in this area. The reasons are as following; (1) the population growth rate in this area is gradually decreasing because of smaller family in big city, (2) people in urban area is generally using more luxury facility that consume higher rate of water for example bathing with shower changed from bowl, washing by machine, and etc.

Table 7.3 shows household water demand in case of constant and varied water use unit. In case of constant water use unit, household water demand in year 2025 was 1,112 MCM or increasing 16 % from year 2006 but in case of varied unit, household sector needs 1,769 MCM or more 84 % from year 2006. The policy makers should concern this rapid change and prepare countermeasures to decrease this demand. There are many interesting measure from case of Tokyo in Japan as following; (1) pricing policy with adopting two part tariff considering of minimum charge (varied by pipe diameter) and community charge (varied by increasing block rates), (2) customer service promotion plan concentrated to provide plain information to safe water and understand customer need, (3) efficient utilization of water including reclaimed water in one-building area, small system area, rainfall utilization, industrial water, and recycled flushing toilets and watering plants, (4) spread of water saving equipment, (5) promotion of leakage prevention measures, and (6) research and development.

Table 7.3 Household water demand.

Water use unit	Area	Household water demand, MCM				
		2006	2010	2015	2020	2025
Constant	Rural area	907	951	1,018	1,057	1,072
	Urban area	49	47	41	37	38
	Total	956	998	1,059	1,095	1,112
Varied	Rural area	909	1,035	1,235	1,462	1,730
	Urban area	49	47	41	37	38
	Total	962	1,083	1,276	1,500	1,769

Policy makers have government option scenarios to make decision as shown in table 7.4 including constructing new water infrastructures, leakage reduction system, and subsidy. The suitable choice depends on policy makers' evaluation standard. If the standard is maximum net benefit, the suitable measures are case 1 and 4. However, case 4 has lower user's satisfaction. It is possible that this dissatisfaction will change to the social and political problem. If the evaluation standard is to maximize users satisfaction, case 1 and 3 are suitable. The reason that leakage reduction system is not effective is because the unit cost of raw water is very cheap approximately 0.30 THB/m^3 (average cost of raw water in all rivers) compared with unit cost of leakage reduction system at 2.37 THB/m^3. The objective of case 4 is to calculate the unit cost of raw water bought from

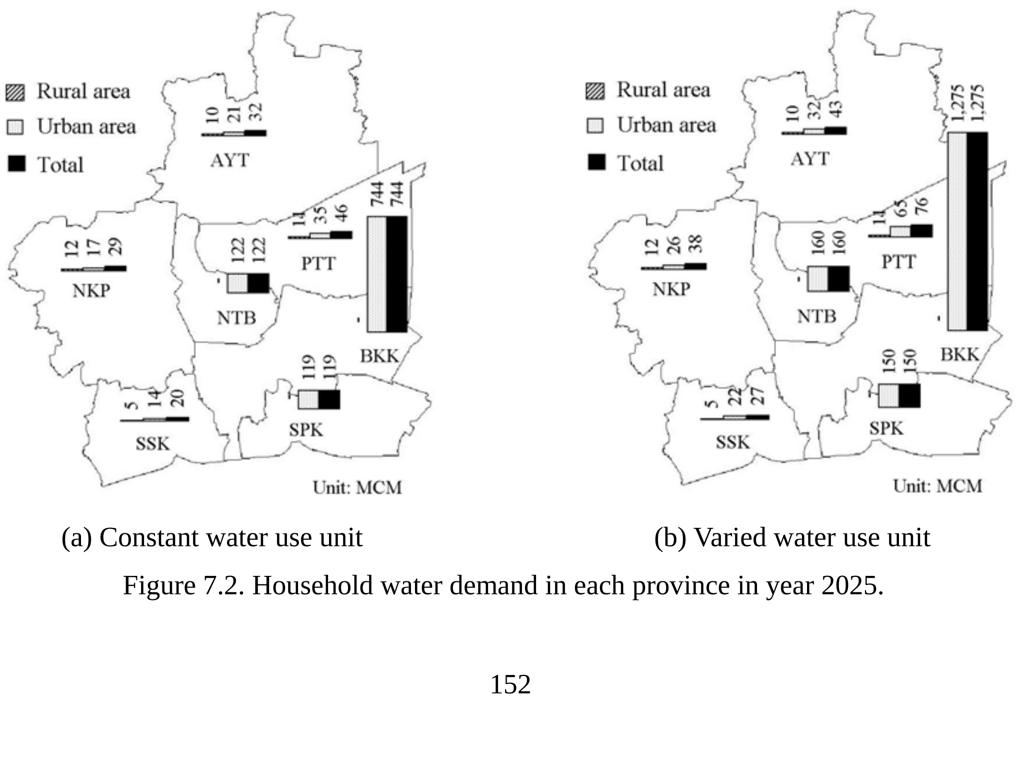
RID that produce net benefit as same as case 1. It means that now the leakage reduction system is not effective because of very low cost of raw water bought from RID but if the unit cost of raw water is 1.41 THB/m^3 or 4.7 times of raw water's price in present time, the leakage reduction system should be invested. However, the suitable solution depends on each evaluation standard should be designed by policy makers.

Table 7.4 Effects from government option scenarios of household sector in year 2025.

	Unit	Case 1 Inf-NoLeak -Nosub	Case 2 NoInf-Leak -Nosub	Case 3 NoInf-Leak -Sub	Case 4 NoInf-Leak -Sub *
New water supply		With	Without	Without	Without
Leakage reduction		Without	With	With	With
Subsidy system		Without	Without	With	With
Total benefit	10^6 THB/d	290.9	291.1	291.0	292.1
Total cost	10^6 THB/d	0	0.3	1.2	1.2
Net benefit	10^6 THB/d	290.9	290.8	289.8	290.9

Note: 1. * for case 4, the net benefit will equal to case 1 if the price of raw water bought form RID is higher than 1.41 THB/m^3, 2. 36.3 Thai Baht (THB) = 1 U.S. Dollar (USD) at Dec 22, 2006.

Figure 7.2 shows household water demand in each province in year 2025. It consists of 2 scenarios; constant and varied water unit. The main water consumer in household sector is mainly lived in Bangkok, the capital of Thailand. The main different of water demand between Bangkok and other provinces are number of population, urbanization, and water use unit.



(a) Constant water use unit (b) Varied water use unit

Figure 7.2. Household water demand in each province in year 2025.

7.3 Agricultural sector

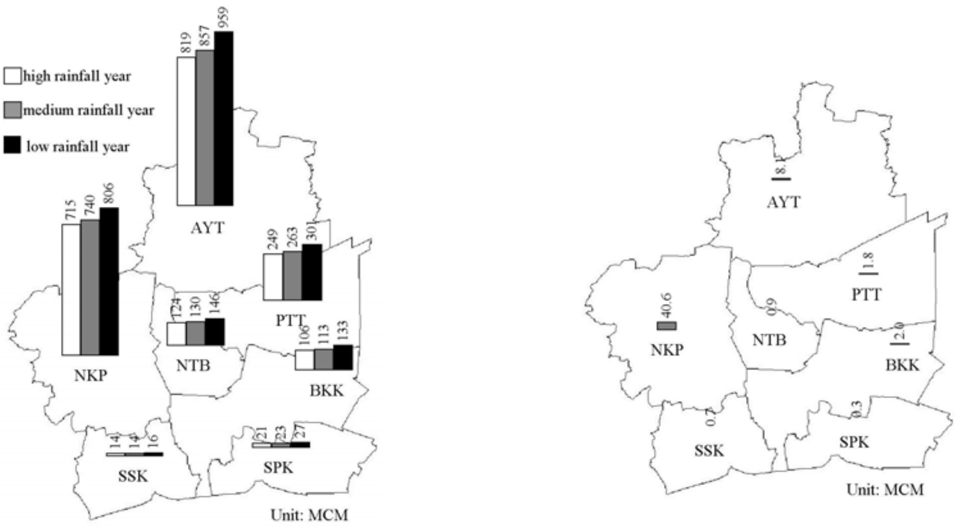
Agricultural sector in figure 7.5 generally consumed water in high percentage of total use especially rice. Only rice and sugarcane is mainly planted in study area because of physical soil condition of clay in the lower part. Agricultural sector is differently analyzed from industrial and household sector because farmer can use water with free of charge in Thailand. It means that pricing policy cannot use in this sector. Main effects for agricultural water demand are crop demand and climate. Crop demand depends on world and national market as shown in chapter 6. Irrigation sector is not the main economic activity in this area because of high density of factory but consume much water if compared with other sectors. Main water user in agricultural sector is irrigation approximately 97 % of total as shown in figure 7.3. However, livestock water demand concentrated in Nakon Pathom should be considered in topic of environmental viewpoint because of wastewater from swine or pig and chicken.

Table 7.5 Agricultural water demand.

Sector	Rainfall	Agricultural water demand, MCM				
	year	2006	2010	2015	2020	2025
Irrigation	Low	2,301	2,313	2,351	2,386	2,388
	Medium	2,041	2,055	2,096	2,135	2,141
	High	1,942	1,959	2,000	2,040	2,048
Livestock		28	31	36	44	54
Agricultural	Low	2,329	2,344	2,387	2,430	2,442
	Medium	2,069	2,086	2,132	2,179	2,195
	High	1,970	1,990	2,036	2,084	2,102

7.4 Total water demand

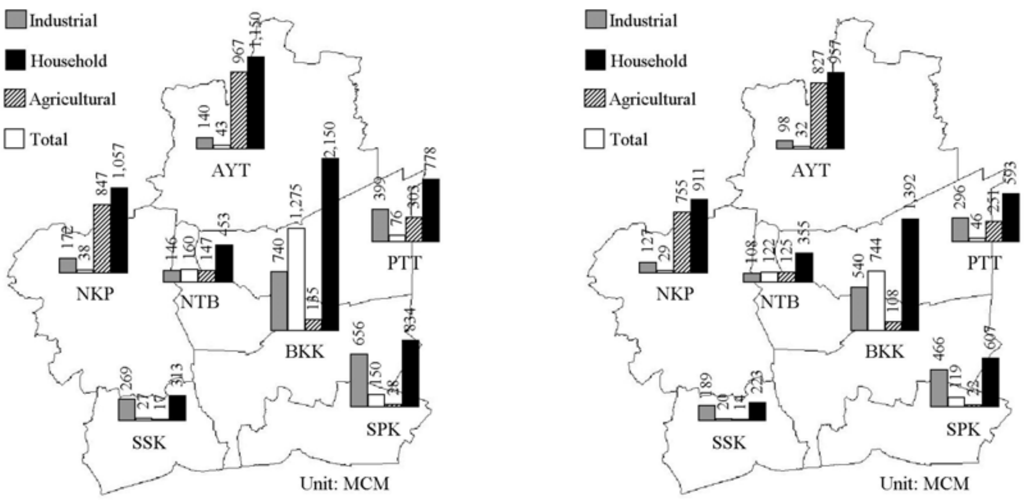
Total water demand including industrial, household, and agricultural sector was shown in table 7.6. Total water demand was varied from the possible maximum and minimum case between 5,038 and 6,734 MCM depended on situations in each sector. Possible maximum water demand is summation of industrial water in case 4 or all declared strategies, household water in case of varied water use unit and agricultural water in case of low rainfall. If 100 % of possible recycled water in Japan case was applied, it can be saved approximately 573 MCM in year 2025 or approximately 60 % of capacity of Pasak dam or 30 % of water demand in Tokyo in 2003.



(a) Irrigation sector (b) Livestock sector

Figure 7.3. Agricultural water demand in each province in year 2025.

Figure 7.4 shows total water demand in each province of year 2025. It can be divided into 2 groups; mainly agricultural and non-agricultural users; (1) Agricultural group consists of Ayutthaya and Nakon Pathom, (2) Bangkok, Pathumthani, Nontaburi, Samut Prakan and Samut Sakorn as non-agricultural group. The main different is clearly in household sector of Bangkok. Bangkok is the capital of Thailand including fully development of waterworks and high quality of urban area in big city. It is certain that economic activities for urban sector in this area consume much water.



(a) Maximum case: T.1. (b) Minimum case: T.2.

Figure 7.4. Total water demand in each province in year 2025.

Table 7.6 Total water demand in Lower Chao Phraya River Basin.

Sector			Industrial water demand, MCM				
			2006	2010	2015	2020	2025
Industrial sector							
I.1.	Normal growth rate		712	881	1,140	1,456	1,824
I.2.	Normal Gr with Ind master plan		738	958	1,318	1,792	2,398
I.3.	Normal Gr. with Ind master plan and FTA with Global.		753	978	1,347	1,833	2,453
I.4.	Normal Gr. with Ind master plan and FTA with USA, China, and Japan.		773	1,004	1,384	1,884	2,523
Industrial recycled water; percentage of possible maximum recycled rate in Japan case with case of I.4.							
R.1.	50 % of possible maximum recycled rate		-19	-27	-65	-127	-287
R.2.	100 % of possible maximum recycled rate		-38	-54	-129	-254	-573
Household sector							
H.1.	Constant water use unit		956	998	1,059	1,095	1,112
H.2.	Varied water use unit		962	1,083	1,276	1,500	1,769
Agricultural sector							
A.1.	Low rainfall year		2,329	2,344	2,387	2,430	2,442
A.2.	Medium rainfall year		2,069	2,086	2,132	2,179	2,195
A.3.	High rainfall year		1,970	1,990	2,036	2,084	2,102
Total water demand							
T.1	Maximum case	= I.4 + H.2 + A.1	4,064	4,431	5,047	5,814	6,734
T.2	Minimum case	= I.1 + H.1 + A.3	3,638	3,869	4,235	4,635	5,038
T.3	T.1 with recycle	= I.4 + H.2 + A.1 + R.2	4,026	4,377	4,918	5,560	6,161

7.5 Water right and sharing

In year 2005, Eastern part of Thailand faced the severe water shortage problem because of continued drought years in that time. The water storage in reservoir is not enough for all activities. This situation mainly affects to the citizen’s quality of life and economic in industrial sector because of this area is one of important industrial area of Thailand. Related governmental agencies tried to supply more water and plan to manage water to prevent the same event in the future. There are many conflicts in that time between industrial and agricultural especially irrigation sector. Farmers don’t want to share limited water to industrial because they want to spare water for planting their crop. Industrial sector have to find new source by themselves. Some factory has to pay unit cost of water up to 100 THB/m^3 to avoid the stopping operation in production. The question is how to manage water demand of each sector in this study area if the same situation as eastern part of Thailand is happened.

One interesting option is that sharing benefit among each user with satisfaction. Now, there is one measure similar as this idea. Metropolitan Waterworks Authority is buying raw water with the unit price of 0.50 THB/m^3 from Tha Chin River which water is property of Royal Irrigation Department. It means that household and industrial sector use water from irrigation sector through process among government agencies. In the future, it is possible that each user can directly share water and benefit in periods of water shortage. However, irrigation sector which give water should receive suitable benefit from industrial and household sector. The next question is what the suitable point of benefit sharing is. Figure 7.5 shows the unit value of water used for process from planting each crop, harvesting and selling the crop product. It is calculated from the final outcome from selling product divided by quantity of used water. This unit value of water shows the minimum benefit that industrial and household have to pay.

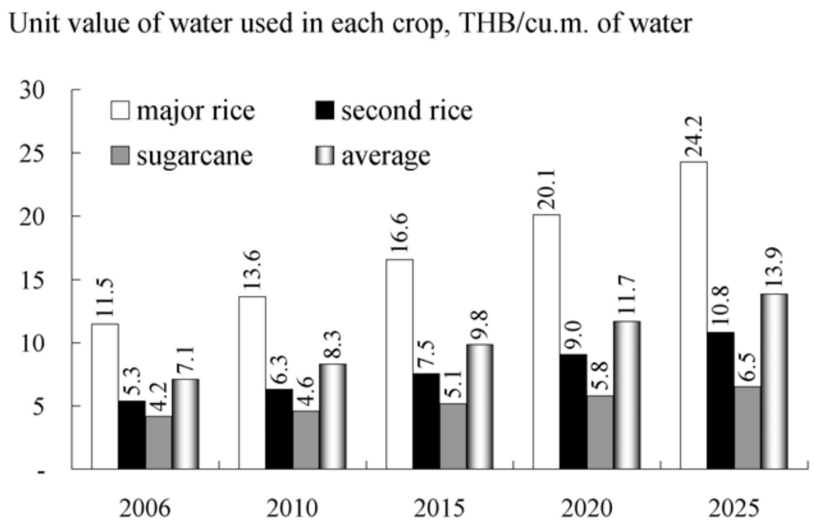


Figure 7.5. Unit value of water used in each crop.

7.6 Recommendation and future research

1. Developing new water sources is more difficult because of limited water supply, conflict with environmental viewpoint, and higher cost of water per cubic meter. Policy maker should use water demand side management especially; (1) water saving such as reuse, reduce, and recycle, (2) pricing policy, (3) water right and sharing, and (4) educate water users with conservation options. Water demand

management invokes ways to operate within limits of current supplies. However, combination of both measures is normally best.

2. In viewpoint of economic, it is almost certain that development of industrial activities need more water for production and utility process. From this reason, policy makers should carefully consider the target of economic with constraints of each water source in specific area. In case of study area, main industrial types such as food and textile concentrated in industrial master plan need groundwater in groundwater critical zone declared by groundwater ban law. It is the conflict between the target of economic and constraint of water in this area. Policy makers should make decision of economic planning with the maximum possible capacity of water.

3. The water rights and sharing in the dry season are always the critical period for water shortage problem. Water management system in Thailand is generally planned from the top-bottom or from central government to users. The problem of this method is that right of water in each user was designed and controlled by policy makers that don't use water in that area. One interesting measure used in Japan is bottom-top method or planning from local committee of each area. The committees consist of only water users in each sector such as factory, farmer, and the head of citizen located in that area. The officers form local-central government and specialists from academic fields play a role as only consultants. By this method, the right and sharing of water and benefit was designed by water users. The suitable solutions are generally buying/leasing/selling water right with satisfying received benefit.

4. This developed water demand management model was concentrate in using economic methods and operation techniques as demand management strategies that are powerful tools for balancing demand and supply. However, the techniques of using society policy such as law, regulations and education to water users are the next interesting topics for this area.

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Appendix A

Schematic diagram in details

Industrial sector

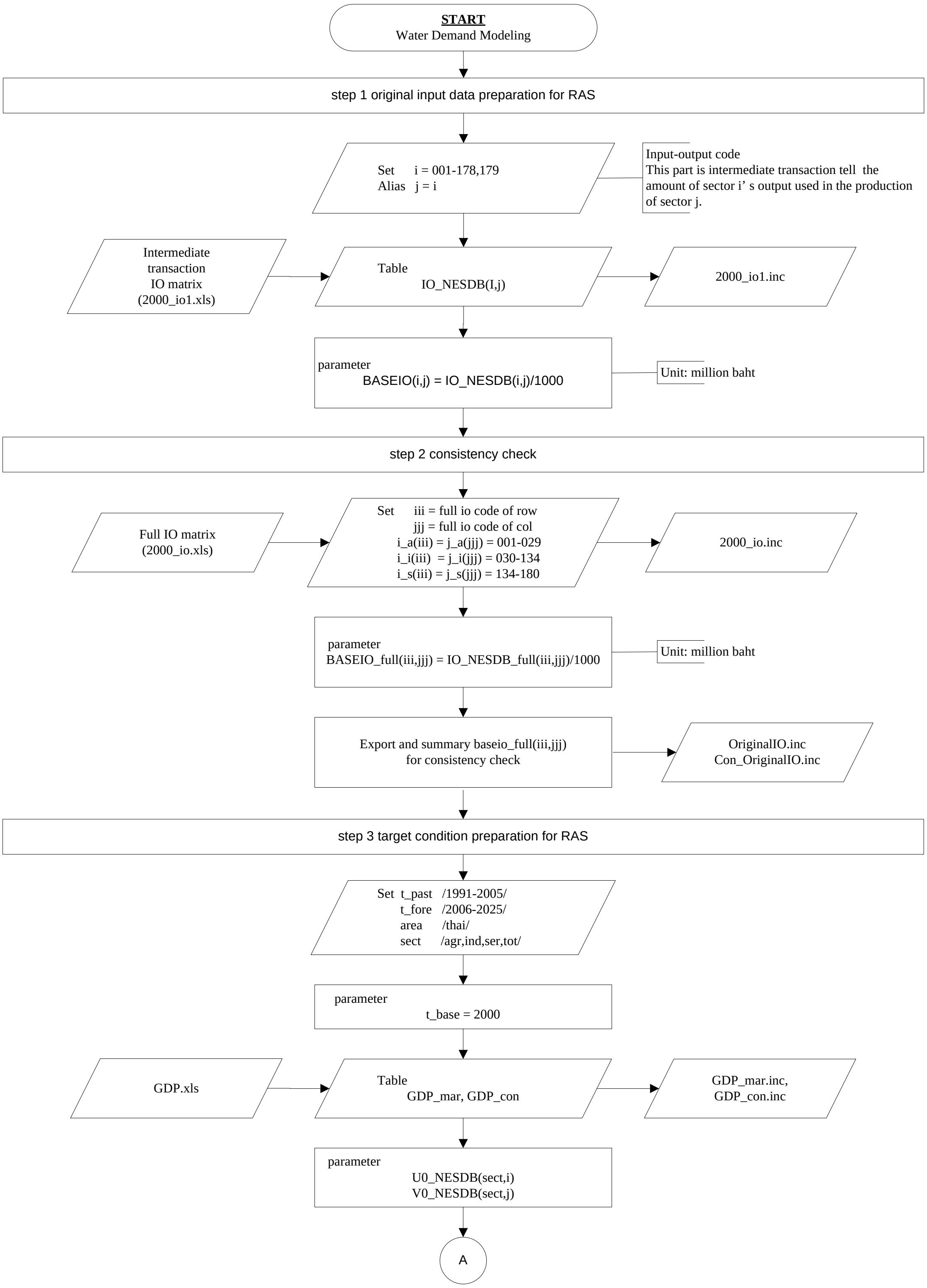


Figure A-1. Schematic diagram of industrial water demand management model

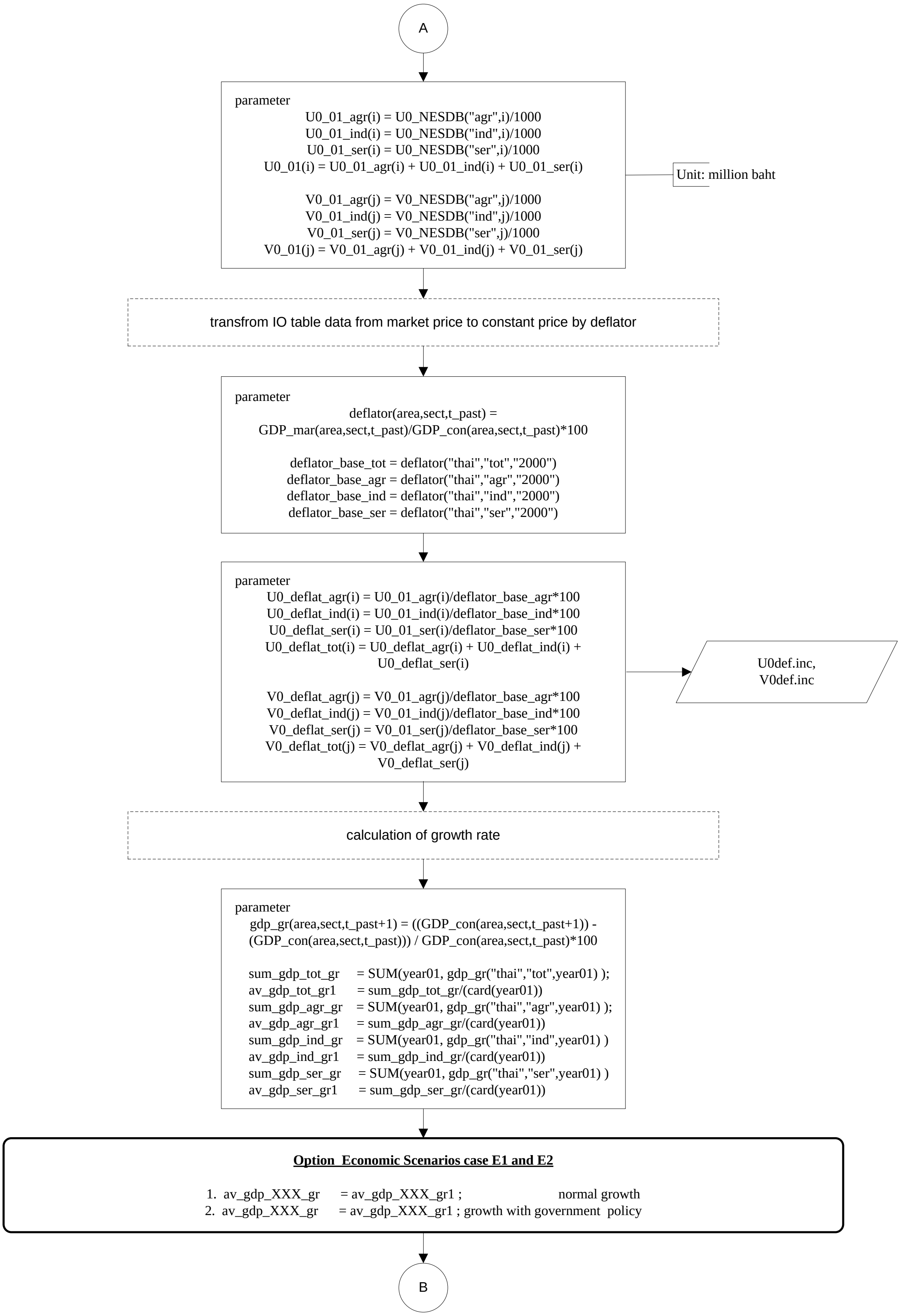


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

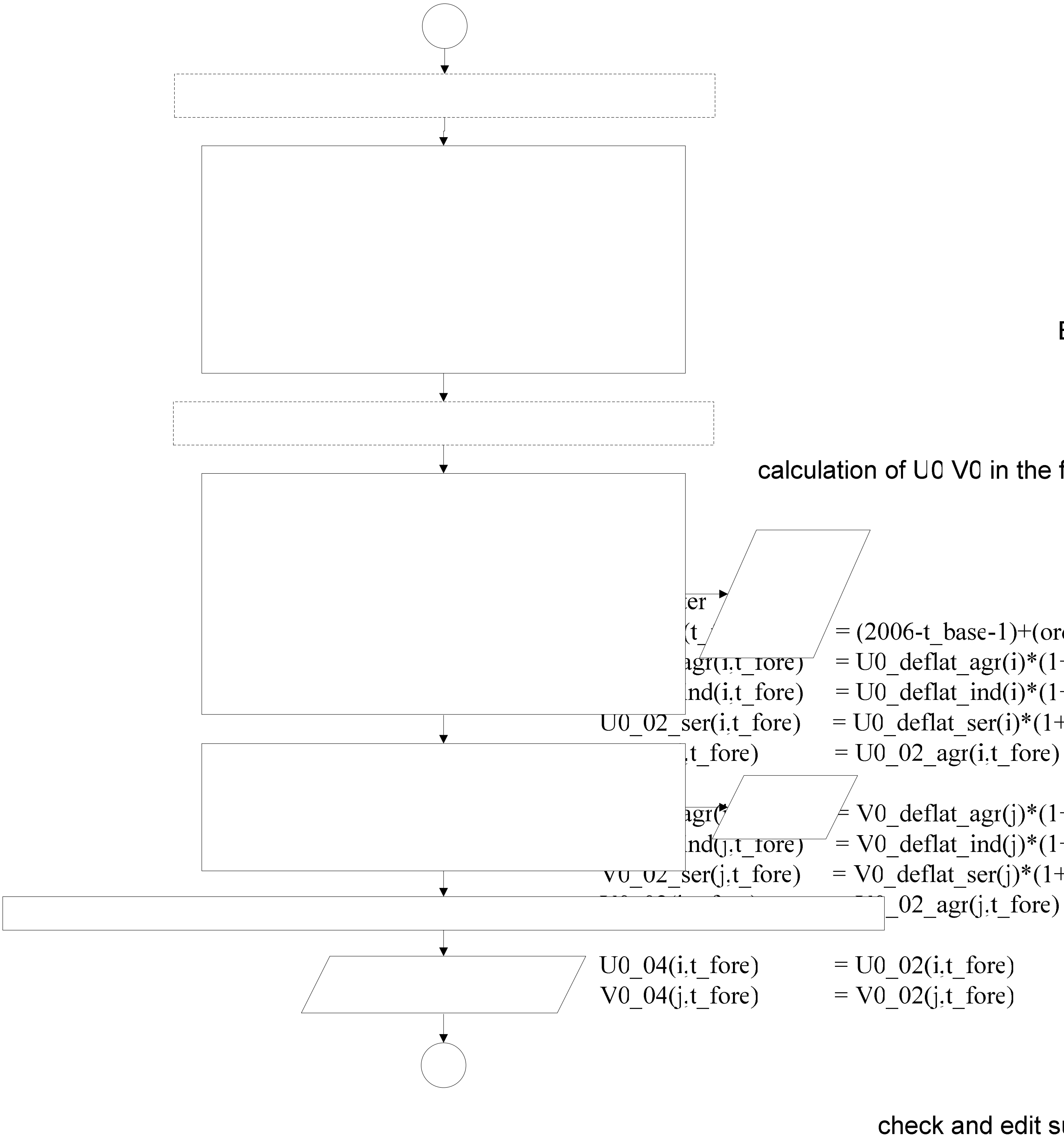


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

parameter
sum_U0_04(t_fore) = SUM(i, U0_04(i,t_
sum_V0_04(t_fore) = SUM(j, V0_04(j,t_
sum_U0V0_04(t_fore) = sum_U0_04(t_fore

U0_05(i,t_fore) = U0_04(i,t_fore)*su
V0_05(j,t_fore) = V0_04(j,t_fore)*su

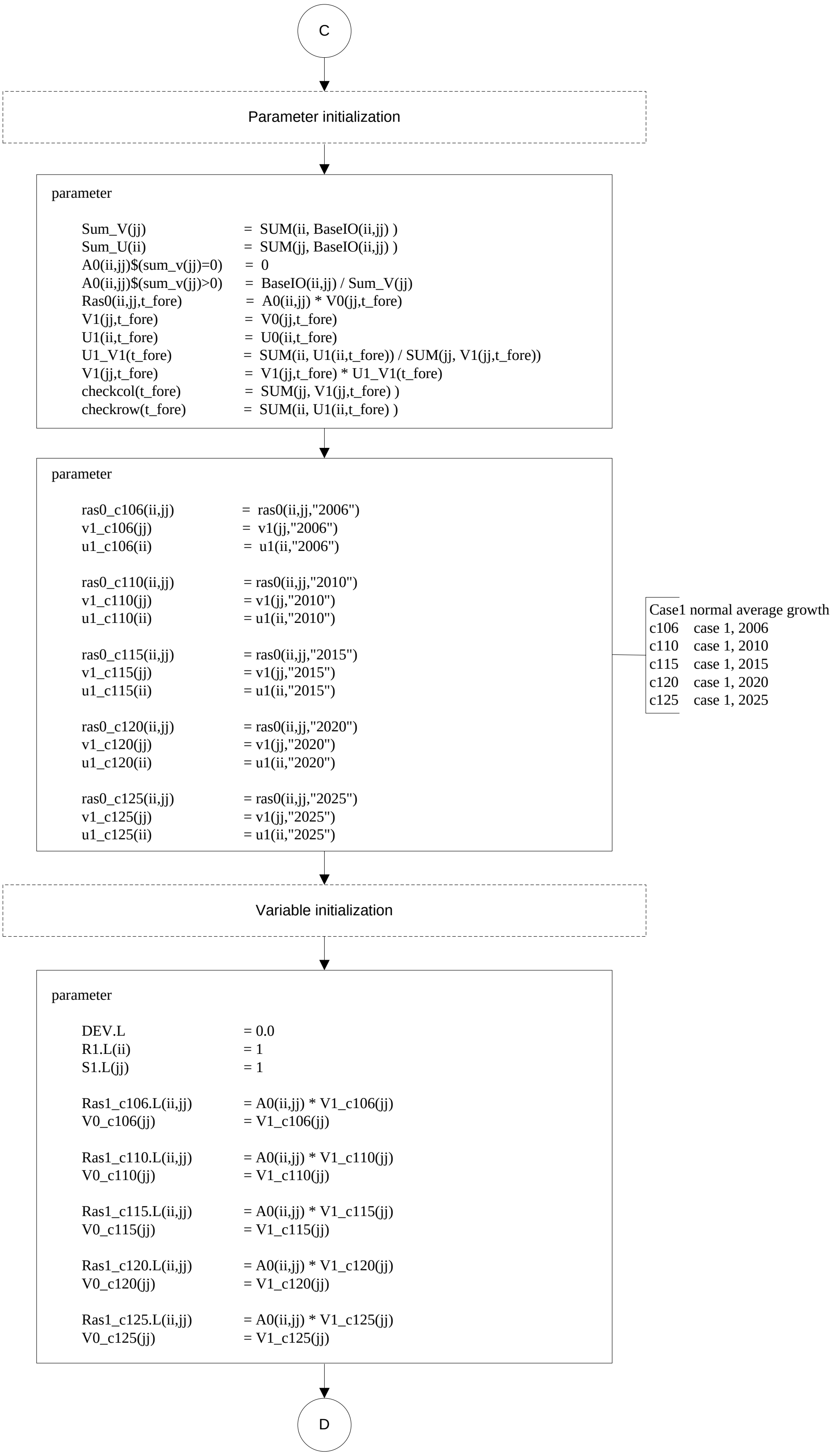


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

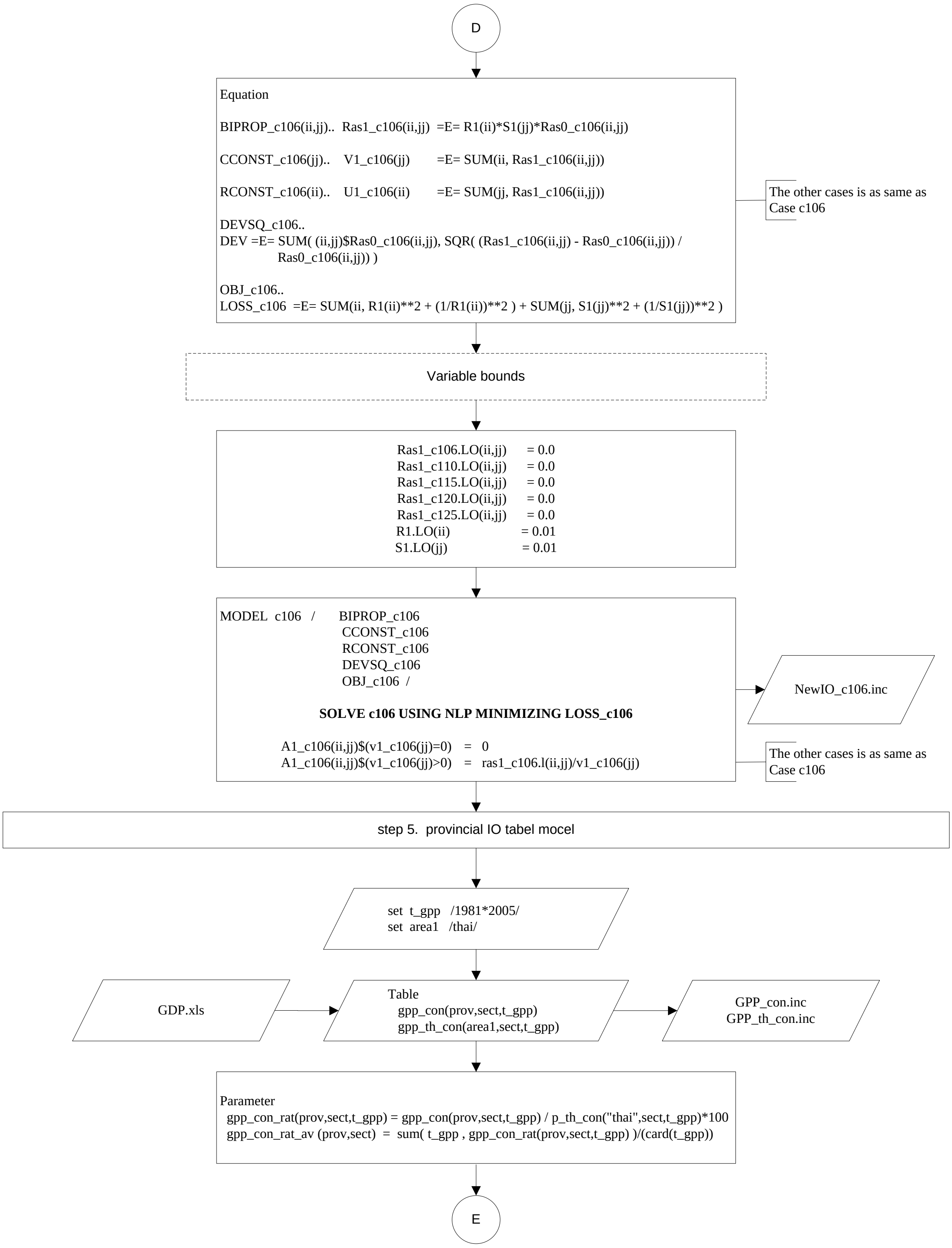


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

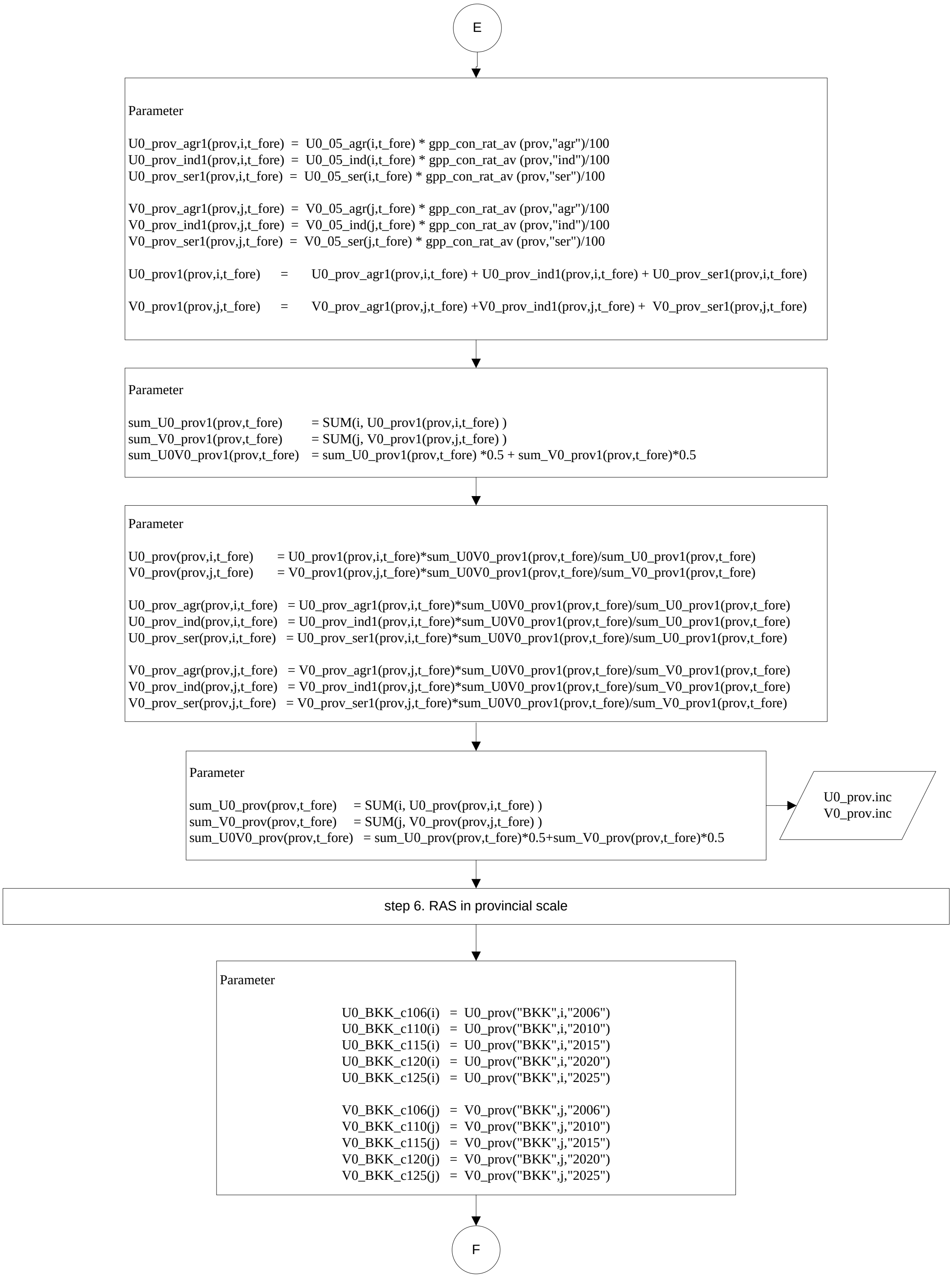


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

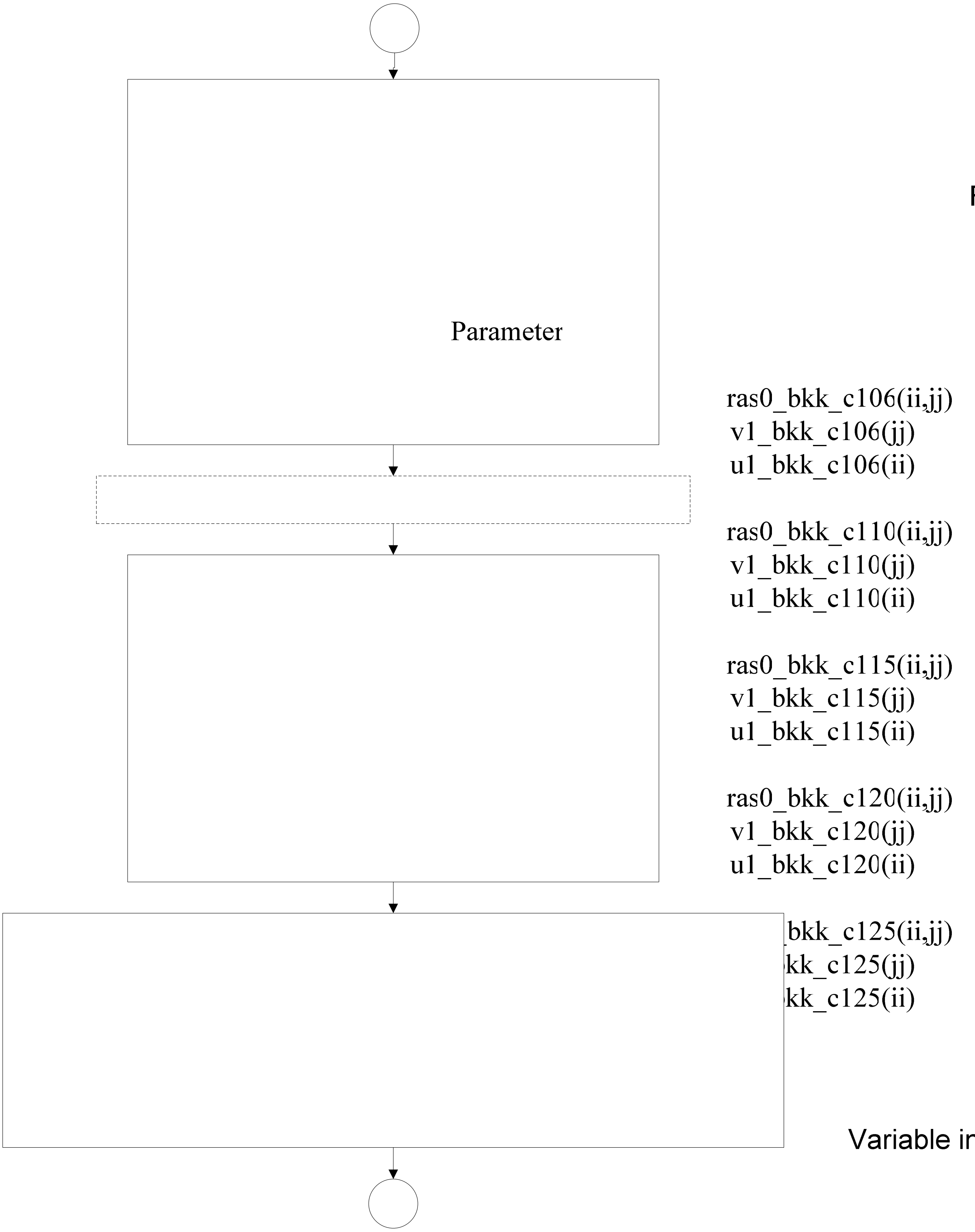


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

DEV.L =
R1.L(ii) =
S1.L(jj) =

Ras1_bkk_c106.L(ii,jj) =
V0_bkk_c106(jj) =

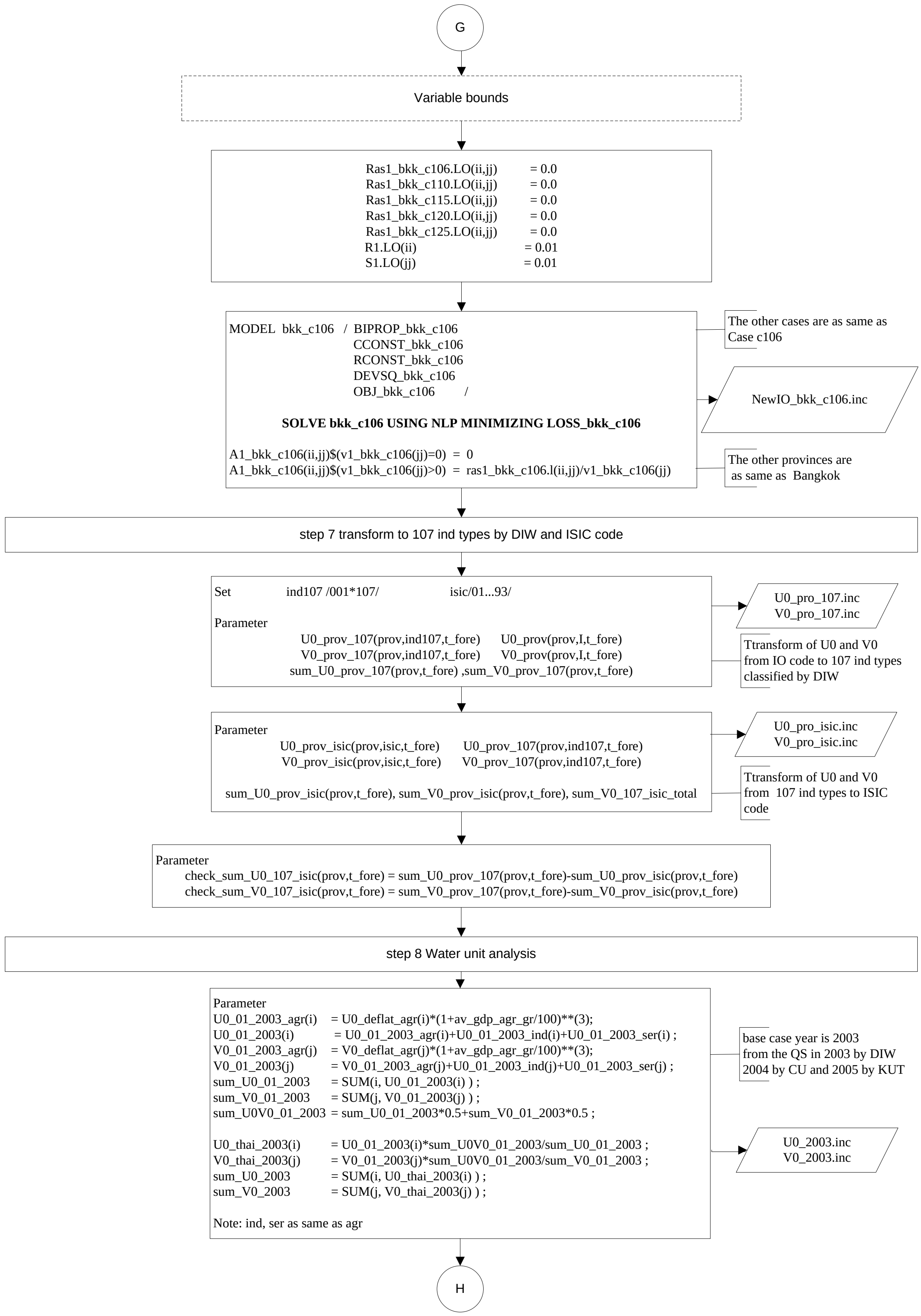


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

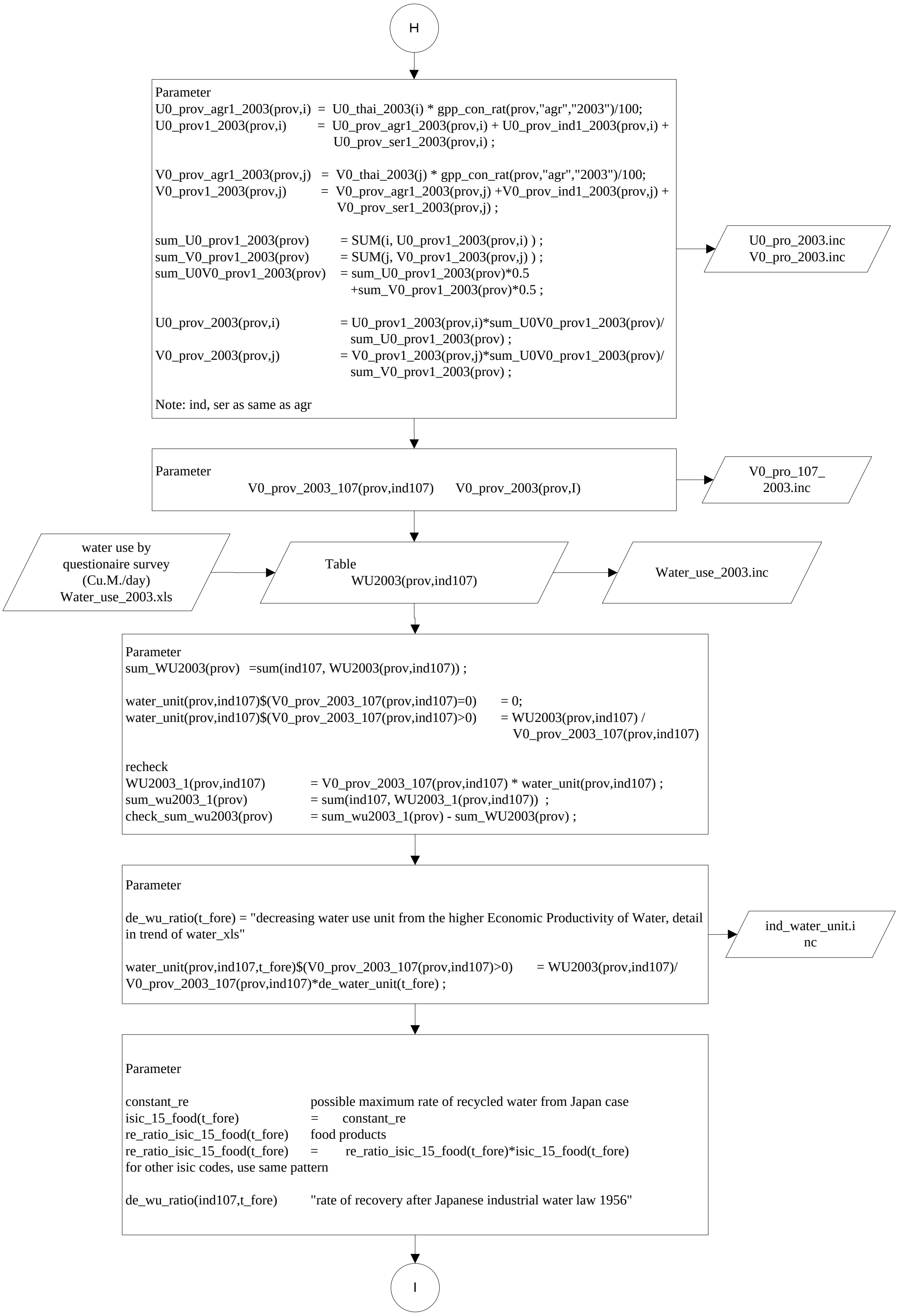


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

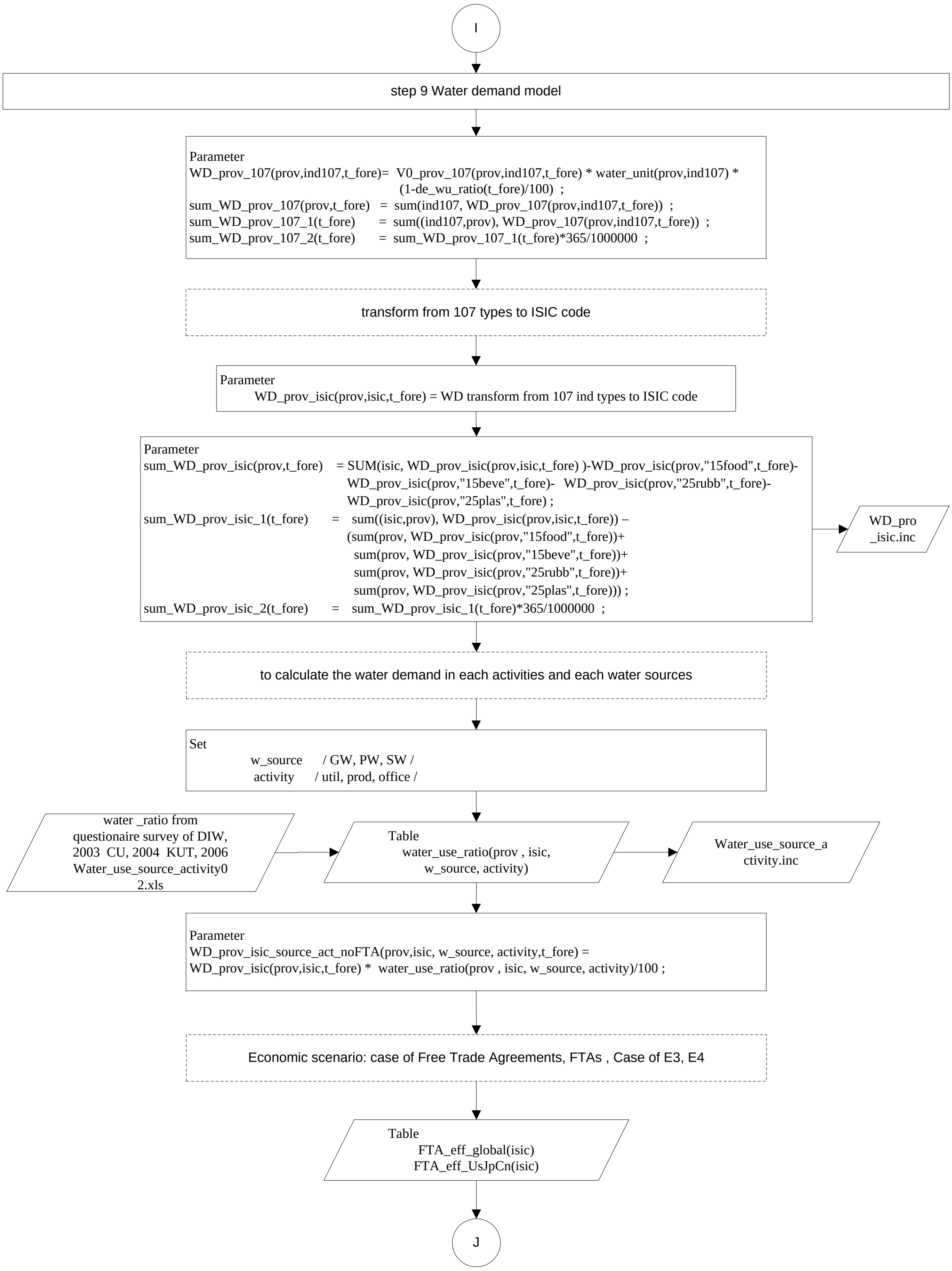


Figure A-1. Schematic diagram of industrial water demand management model (Cont’d)

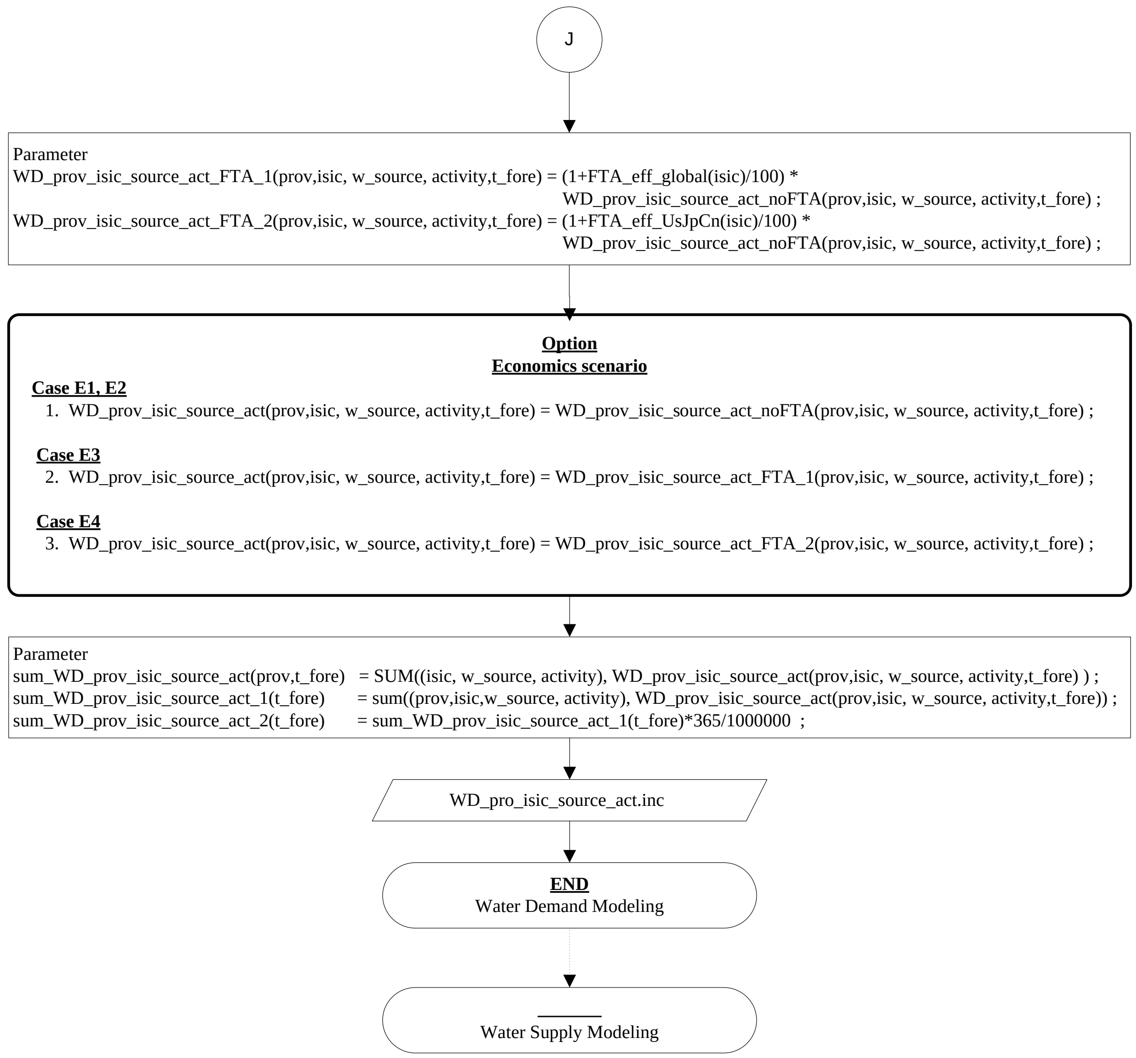


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

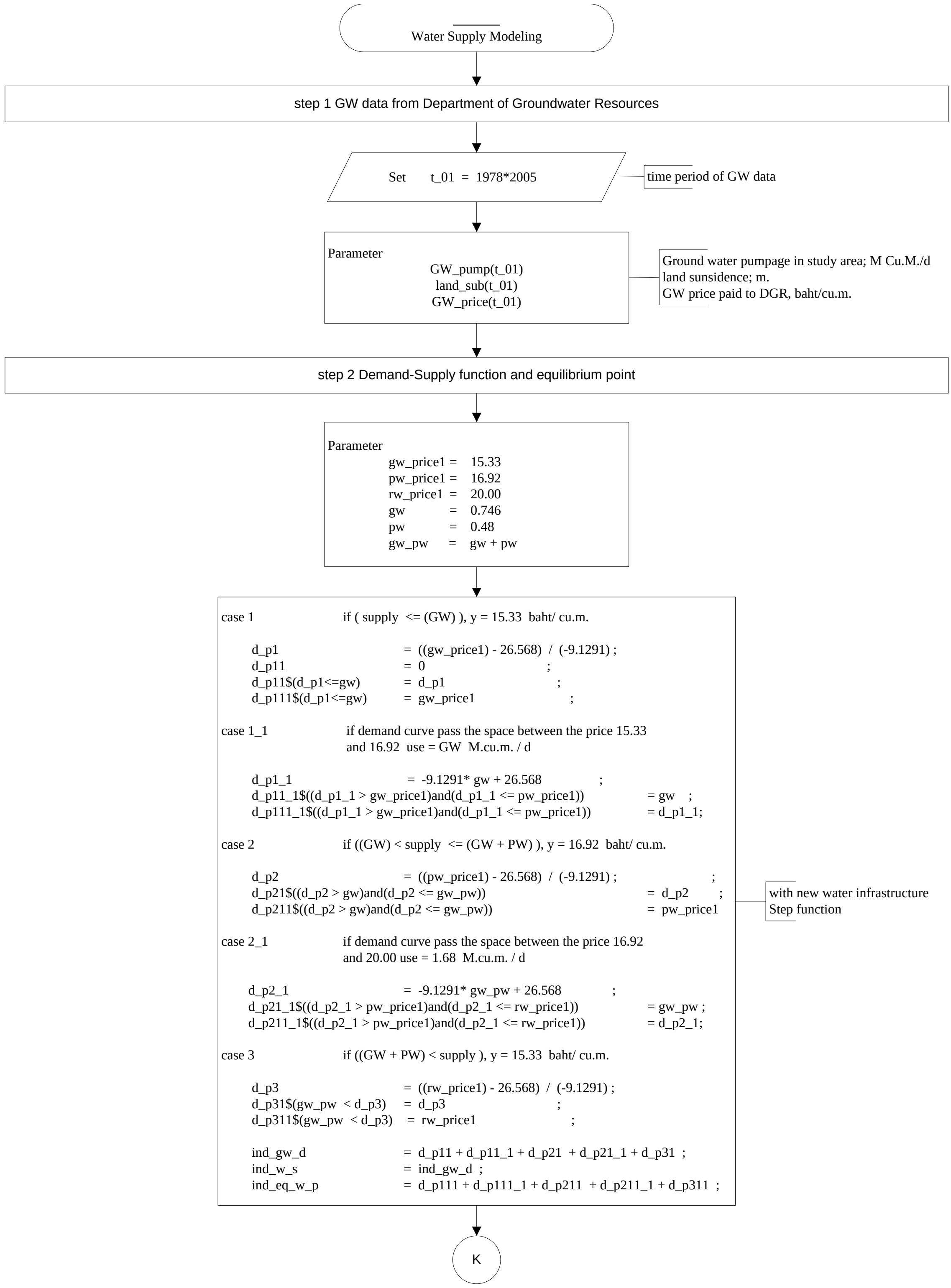
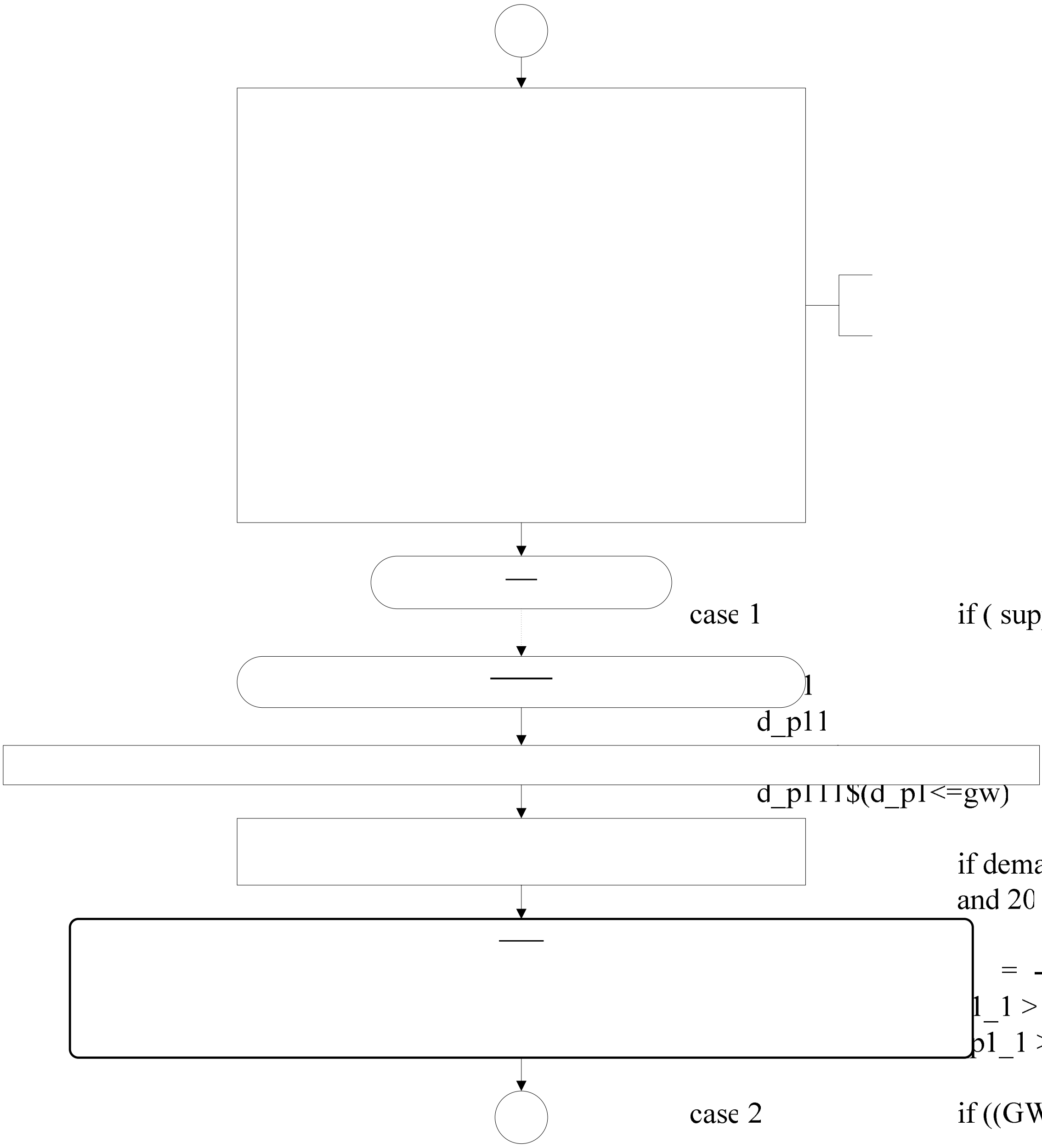


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)



case 1 if (supply <= (GW)), y

1 = ((gw_price
d_p11 = 0
= d_p1
d_p111$(d_p1<=gw) = gw_price1

if demand curve pass the
and 20 use = GW M.cu

= -9.1291* gw + 26.
1_1 > gw_price1)and(d
p1_1 > gw_price1)and(

case 2 if ((GW) < supply), y =

d1_p3 = ((rw_price1) - 26.568)
d1_p31$(gw_pw < d1_p3) =
d1_p311$(gw_pw < d1_p3) =

ind_gw_d1 = d1_p11 + c
ind_w_s1 = ind_gw_d1
ind_eq_w_p1 = d1_p111 +

K

Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

L

Sub-Inf subsidy by government with new infrastructure

```
parameters   ind_gw_use              "industrial groundwater use, M.cu.m
             ind_gw_sup              "water supply function, Baht"
             ind_gw_wtp              "water demand function, Baht"
             ind_gw_sub              "industrial groundwater subsidy, Ba
             ind_gw_reserve          "reserved industrial groundwater fro
                                      Million Baht/d."
             ind_gw_land_sub         "industrial groundwater from protec
*             land subsidence was analyzed from flood damage function in Ba
*             if land sub > 17.9 cm. damage = LS*193.75-3475  million baht
             ind_gw_IT               "Intermediate transaction calculated
             ind_gw_sub_total        "cost from governmental subsidy, M
             ind_gw_sub_loss         "cost - citizen's satisfaction from go
             ind_gw_recharge         "cost from groundwater recharge to
             ind_gw_policy_Sub_Inf   "governmental option scenarios nam
                                      with new infrastructure"
             ind_gw_use_value        "value of IT calculated from ind_gw
             ind_pw_use_value        "value of IT calculated from ind_pw
             ind_sw_use_value        "value of IT calculated from ind_sw
             ind_tot_use_value       "value of IT calculated from ind_tot
             ind_gw_D_value          "value of IT calculated from ind_gw
             ind_pw_use              "industrial tap water use, M.cu.m./d
             ind_sw_use              "industrial surface water use, 10^12
             ind_tot_use             "industrial total water use, 10^12.cu

             ind_gw_use              =  sum_WD_prov_isic_source_act_
             ind_pw_use              =  sum_WD_prov_isic_source_act_
             ind_sw_use              =  sum_WD_prov_isic_source_act_
             ind_tot_use             =  ind_gw_use + ind_pw_use + ind_
             ind_gw_use_value        =  0.0002*(ind_gw_use*365)**4 - 0
                                         1718.6*(ind_gw_use*365)  + 91
             ind_pw_use_value         =  0.0006*(ind_pw_use*365)**4 -
                                         680.80*(ind_pw_use*365)  + 32
             ind_sw_use_value        =  0.044 *(ind_sw_use*365)**4 - 6.
                                         556.91*(ind_sw_use*365)  + 11
             ind_tot_use_value       =  ind_gw_use_value + ind_pw_use
             ind_gw_D_value          =  0.0002*(ind_gw_D*365)**4   - 0
```

Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

M

effect of rrecycled water

parameter

```
WD_prov_107_4(prov,ind107,t_fore)      "water demand in each year classified by provinces and 107 industrial types"
sum_WD_prov_107_4(prov,t_fore)         "sum of water demand classified by provinces and 107 industrial types"
sum_WD_prov_107_1_4(t_fore)            "CU.m/day; sum of water demand in study area, classified by 107 industrial types"
sum_WD_prov_107_2_4(t_fore)            "annual MCM; sum of water demand in study area classified by 107 industrial types"
ratio_of_recycle4                      recycled water ratio with case of japan

WD_prov_107_4(prov,ind107,t_fore)      = V0_prov_107(prov,ind107,t_fore) * water_unit(prov,ind107,t_fore) *
                                         (de_wu_ratio(ind107,t_fore)/100)
sum_WD_prov_107_4(prov,t_fore)         = sum(ind107, WD_prov_107_4(prov,ind107,t_fore))
sum_WD_prov_107_1_4(t_fore)            = sum((ind107,prov), WD_prov_107_4(prov,ind107,t_fore))
sum_WD_prov_107_2_4(t_fore)            = sum_WD_prov_107_1_4(t_fore)*365/1000000

ratio_of_recycle4                      = sum_WD_prov_107_2_4("2025")/365 ;

ind_gw_use_value4$((ind_gw_use4-gw_pw) >  ratio_of_recycle4)      = 0.0002*((gw_pw+ratio_of_recycle4)*365)**4 -
0.2051*((gw_pw+ratio_of_recycle4)*365)**3 + 64.306*((gw_pw+ratio_of_recycle4)*365)**2 -
1718.6*((gw_pw+ratio_of_recycle4)*365)  + 91402 ;

ind_gw_use_value4$((ind_gw_use4-gw_pw) <= ratio_of_recycle4)      = 0.0002*((ind_gw_use4)*365)**4 -
0.2051*((ind_gw_use4)*365)**3 + 64.306*((ind_gw_use4)*365)**2 - 1718.6*((ind_gw_use4)*365)  + 91402 ;
```

target of industrial economic activity

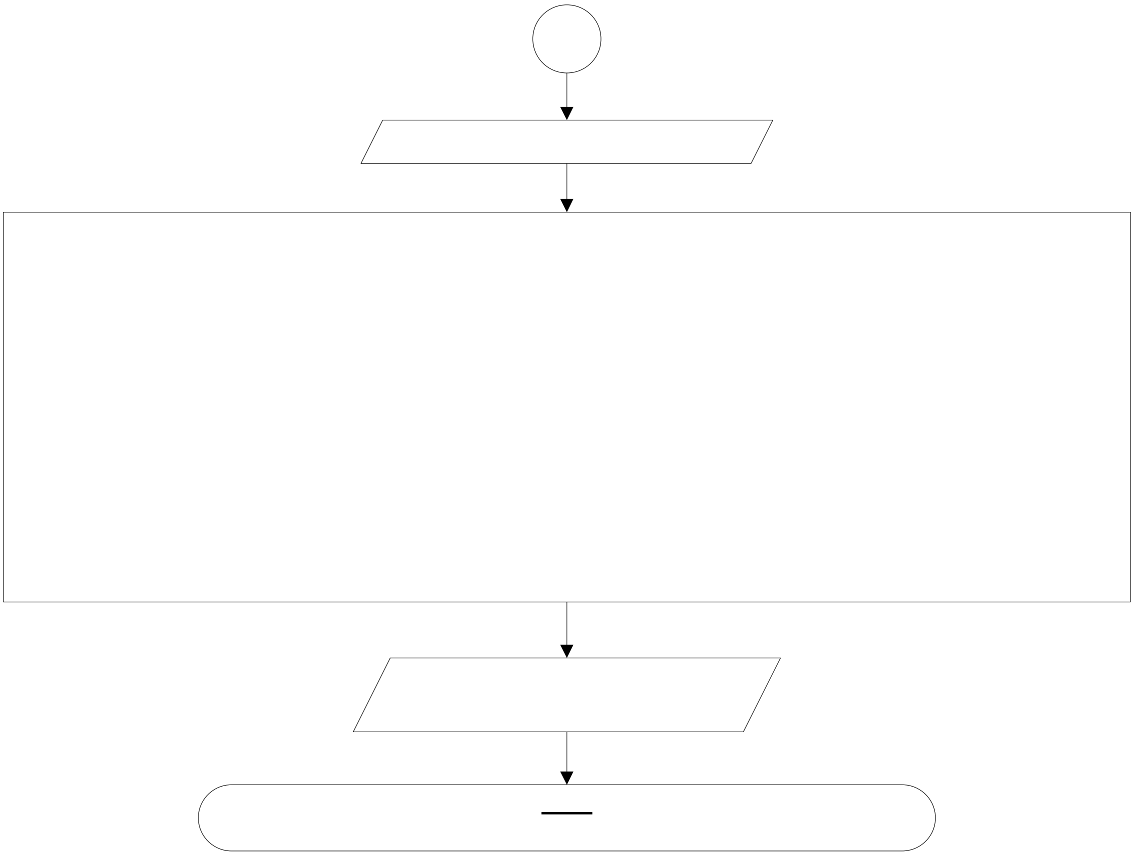
parameters

```
target_ind_policy     =  (0.0002*(sum_WD_prov_isic_source_act_3("gw","2025")/1000000*365)**4 - 0.2051*(sum_WD_prov_isic_source_act_3("gw","2025")/
                         1000000*365)**3 + 64.306*(sum_WD_prov_isic_source_act_3("gw","2025")/1000000*365)**2 -
                         1718.6*(sum_WD_prov_isic_source_act_3("gw","2025")/1000000*365)  + 91402)/1000000   ;
target_ind_policy2    =  target_ind_policy / 365*1000000   ;
target_ind_policy1    =  (target_ind_policy*1000000 + ind_pw_use_value3 + ind_sw_use_value3)/1000000   ;

target_ind_policy3    =  (0.0002*(sum_WD_prov_isic_source_act_3("gw","2006")/1000000*365)**4 - 0.2051*(sum_WD_prov_isic_source_act_3("gw","2006")/
                         1000000*365)**3 + 64.306*(sum_WD_prov_isic_source_act_3("gw","2006")/1000000*365)**2 -
                         1718.6*(sum_WD_prov_isic_source_act_3("gw","2006")/1000000*365)  + 91402)/1000000   ;
target_ind_policy6    =  target_ind_policy3 / 365*1000000   ;
target_ind_policy7    =  (target_ind_policy3*1000000 + ind_pw_use_value3 + ind_sw_use_value3)/1000000   ;

target_ind_policy4    =  ((target_ind_policy1/target_ind_policy7)**(1/(2025-2006))-1)*100 ;
target_ind_policy5    =  av_gdp_ind_gr*target_ind_policy4/target_ind_policy4 ;
```

```
Sub-Inf        subsidy by government       with new infrastructure

parameters     gr_sub_inf2     =  ind_gw_policy_Sub_Inf1 ;
               gr_sub_inf      =  gr_sub_inf2*365/1000000 ;
               gr_sub_inf1     =  (gr_sub_inf*1000000 + ind_pw_use_value3 + ind_sw_use_value3)/1000000   ;
               gr_sub_inf4     =  ((gr_sub_inf1/target_ind_policy7)**(1/(2025-2006))-1)*100 ;
               gr_sub_inf5     =  gr_sub_inf4/target_ind_policy4*target_ind_policy5 ;
               gr_sub_inf6     =  gr_sub_inf5-target_ind_policy5  ;


sub-NoInf      subsidy by government       without    new  infrastructure
               Use as same equations as upper case with number 1

Nosub-Inf      paid by users               with       new  infrastructure
               Use as same equations as upper case with number 2

Nosub-NoInf    paid by users               without    new  infrastructure
               Use as same equations as upper case with number 3
```

N

Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)



N

Con_Gov_Polic

Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

parameter

```
HH_income2(prov,t_fore)        income per household THB
HH_expend2(prov,t_fore)        expenditure per household
lab_mig(isic,t_fore,prov)      labor migration people ;
lab_c0(isic,t_fore,prov)       labor migration coeff ;
lab_c1(isic,t_fore,prov)       labor migration coeff ;
lab_c2(isic,t_fore,prov)       labor migration coeff ;
lab_c3(isic,t_fore,prov)       labor migration coeff ;

lab_mig(isic,t_fore,prov)      = lab_c0(isic,t_fore,prov) +
```

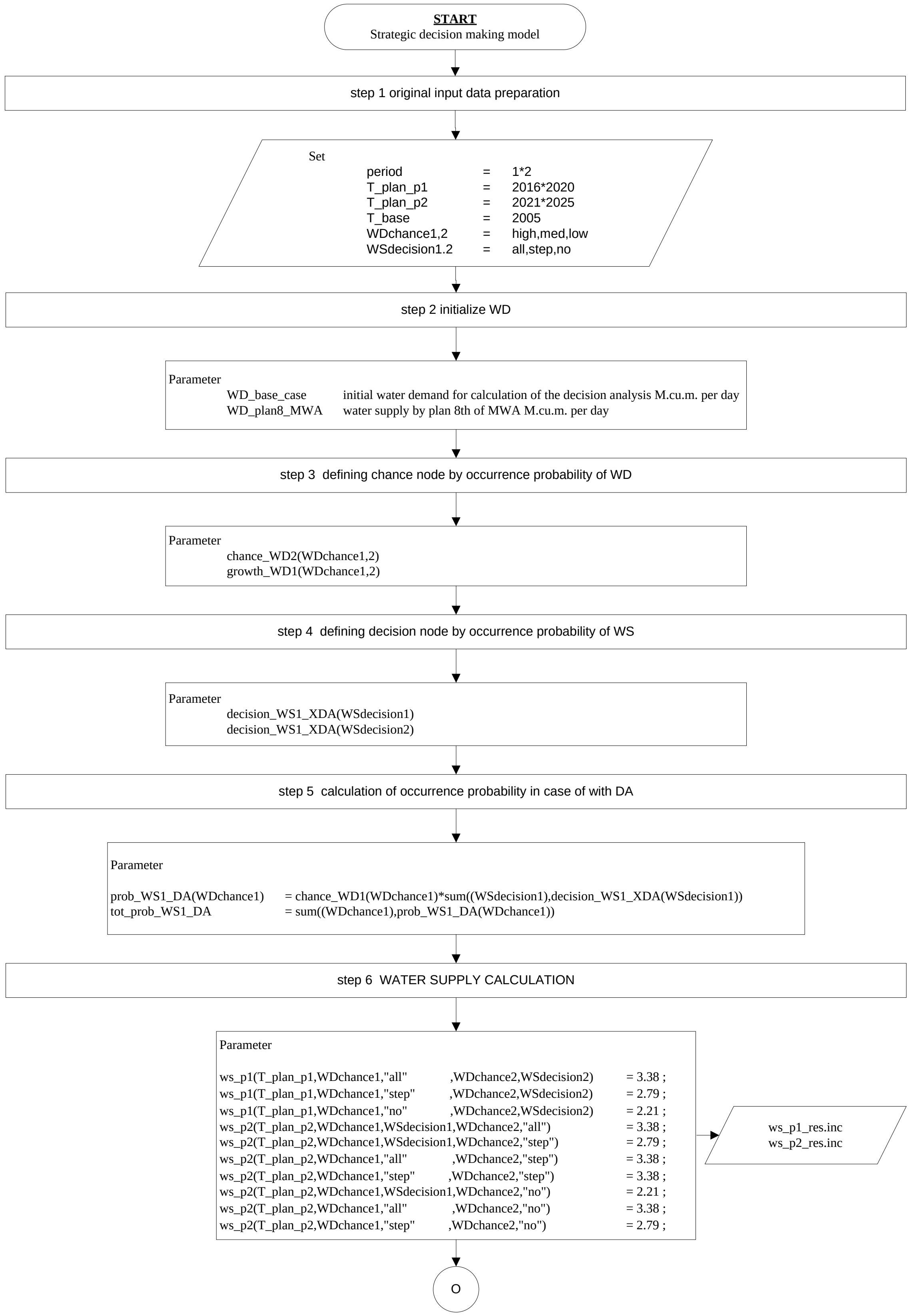


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

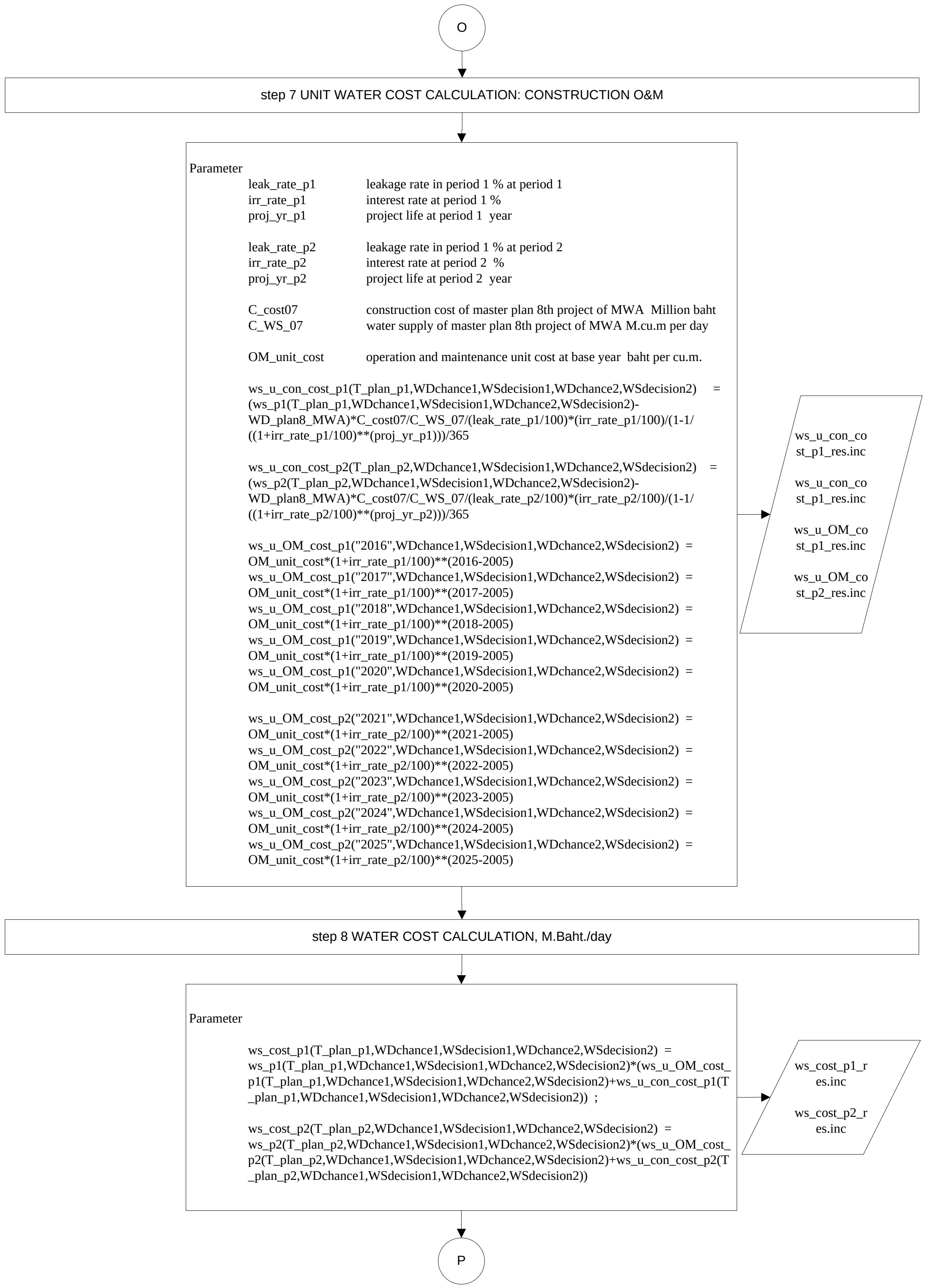


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

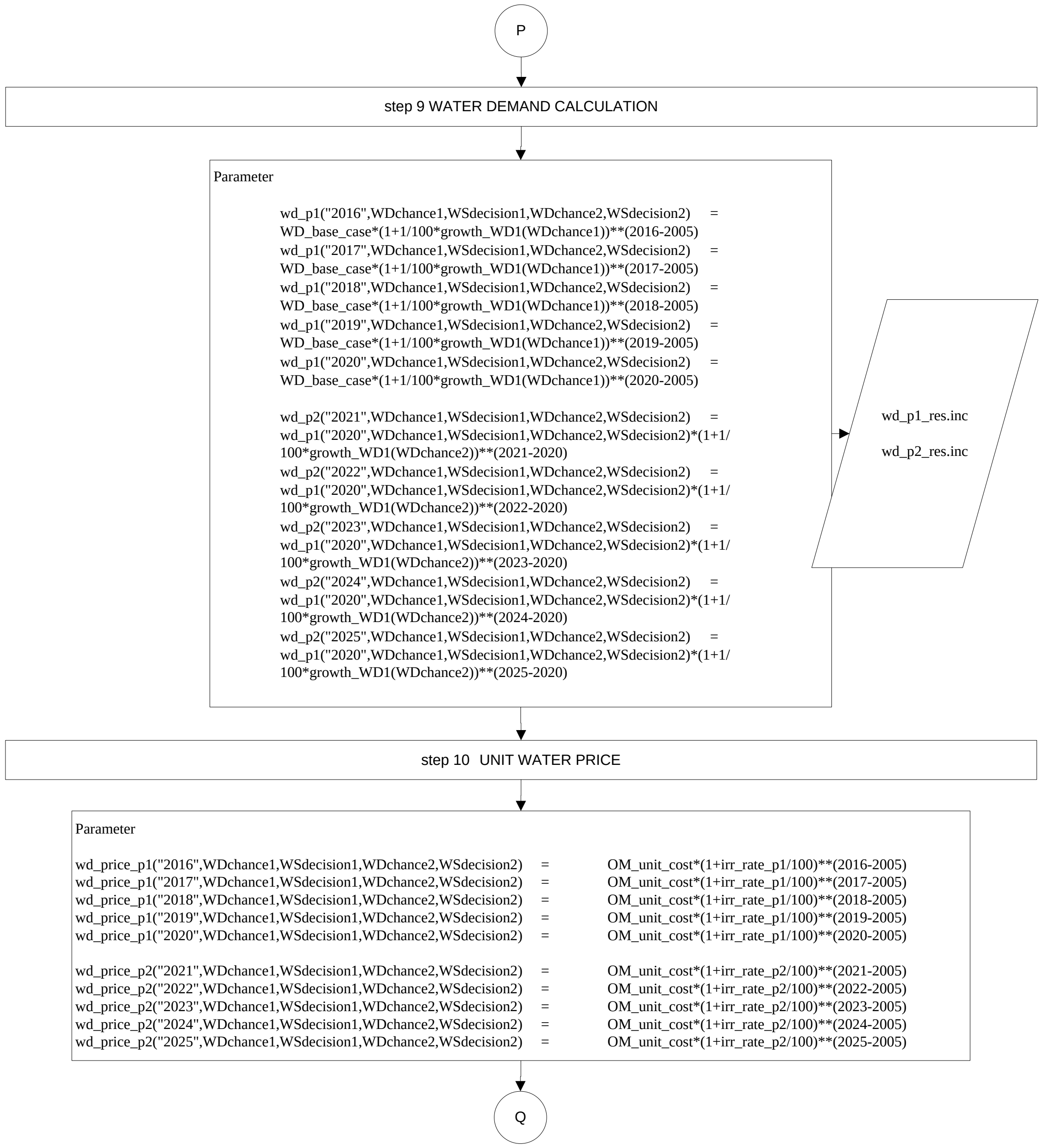


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

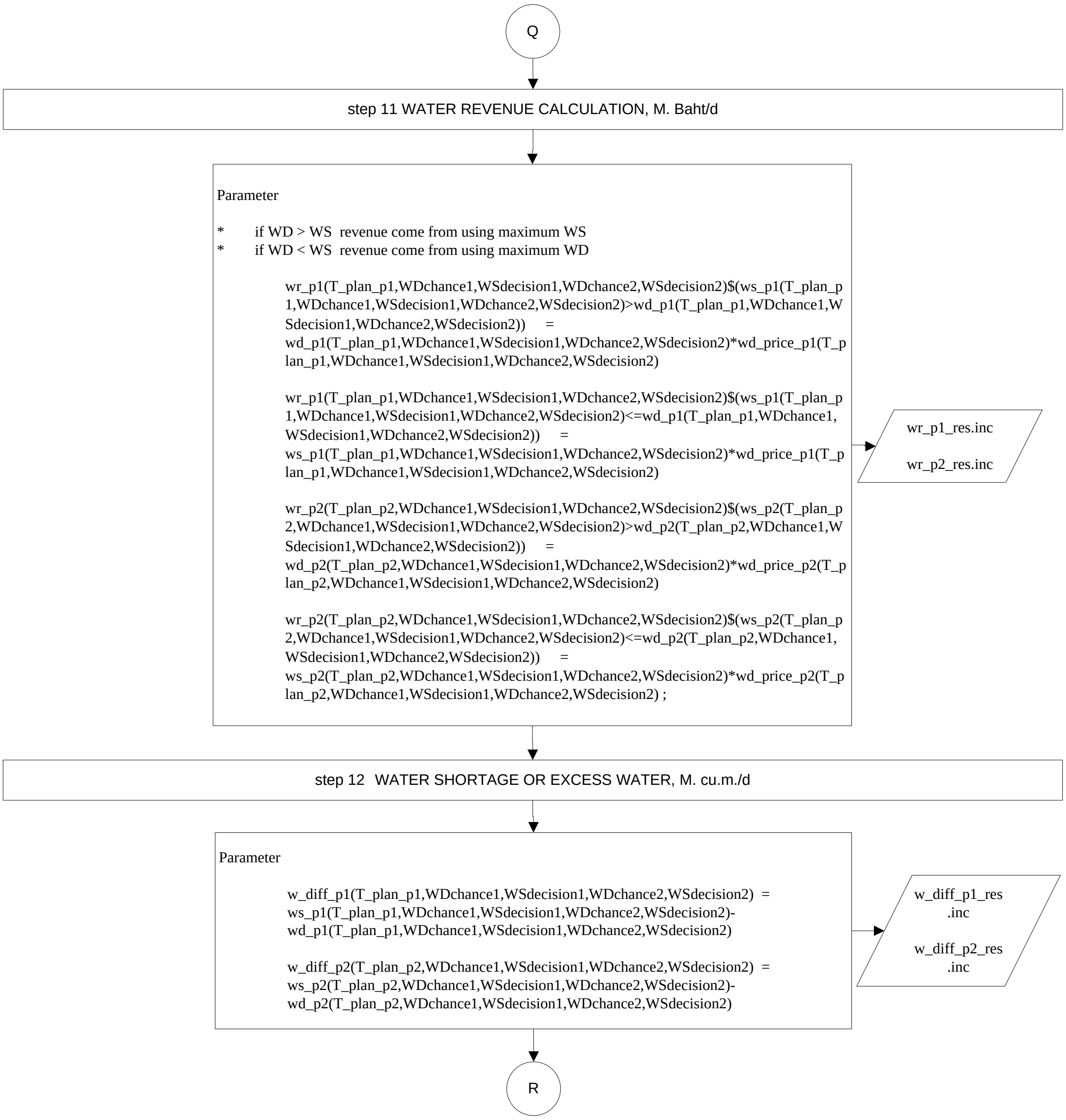


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

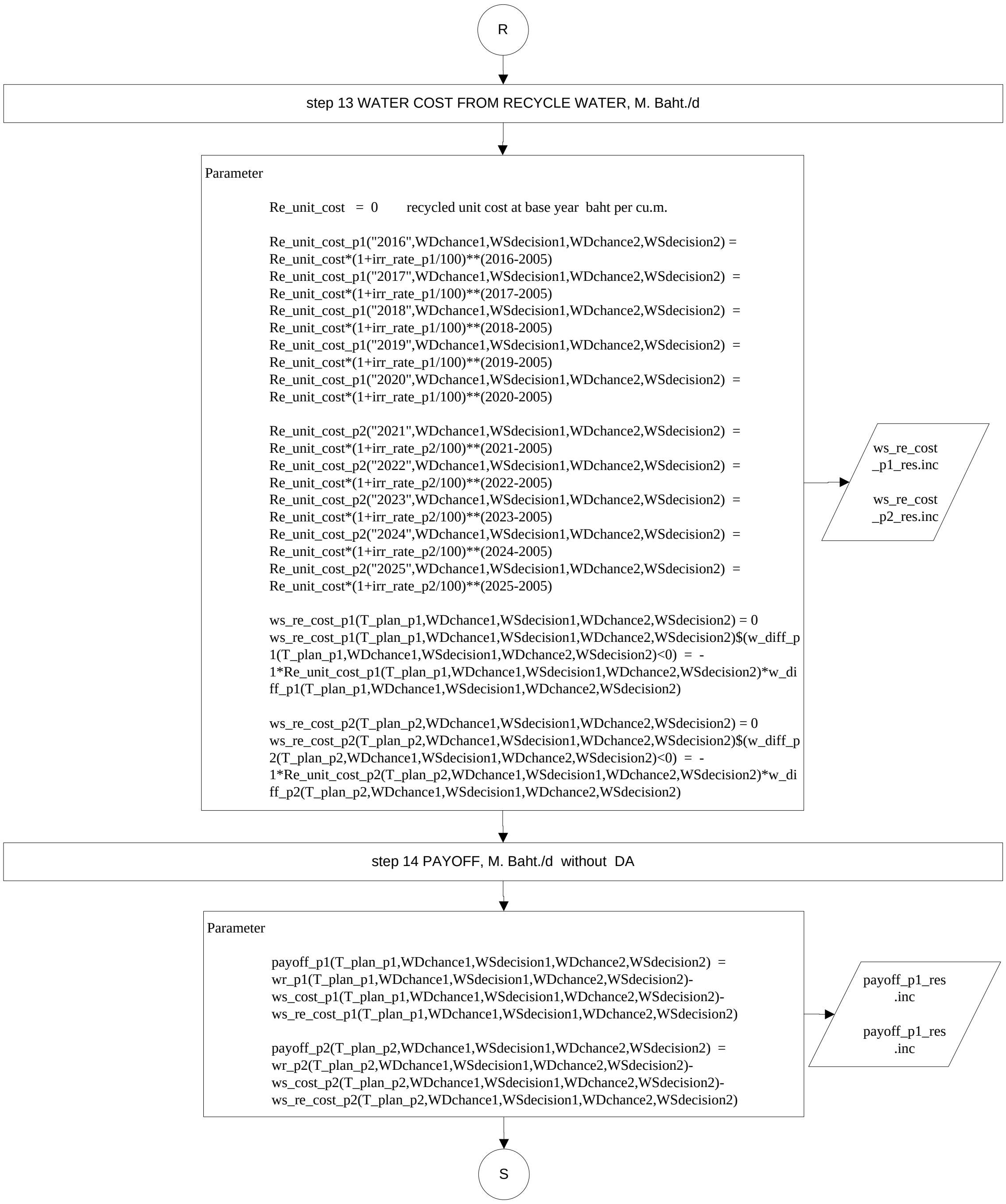


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

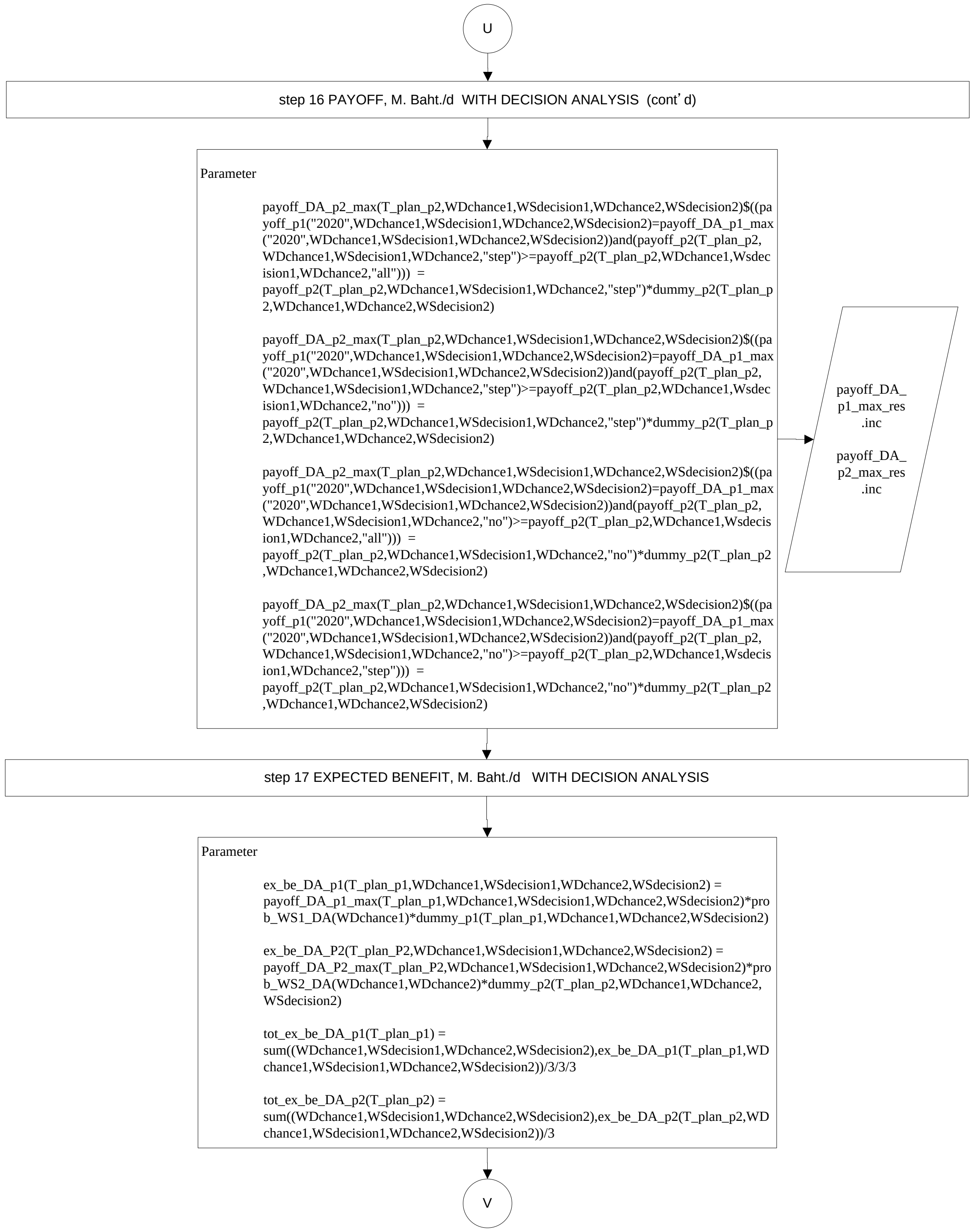


Figure A-1. Schematic diagram of industrial water demand management model (Cont'd)

Figure A-1. Schematic diagram of industrial water demand management model (Cont’d)

Appendix B

Schematic diagram in details

Household sector

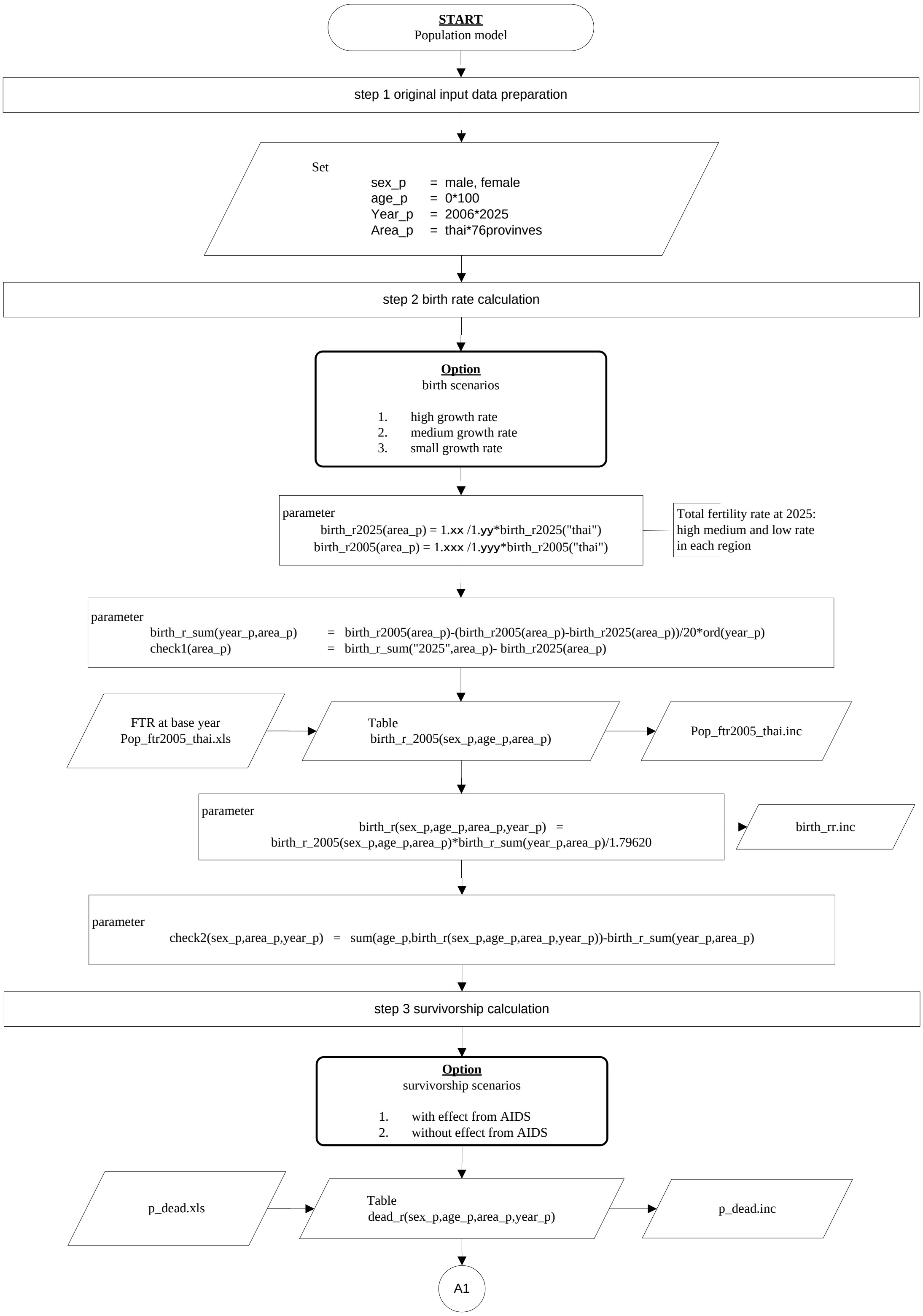


Figure B-1. Schematic diagram of Household water demand management model

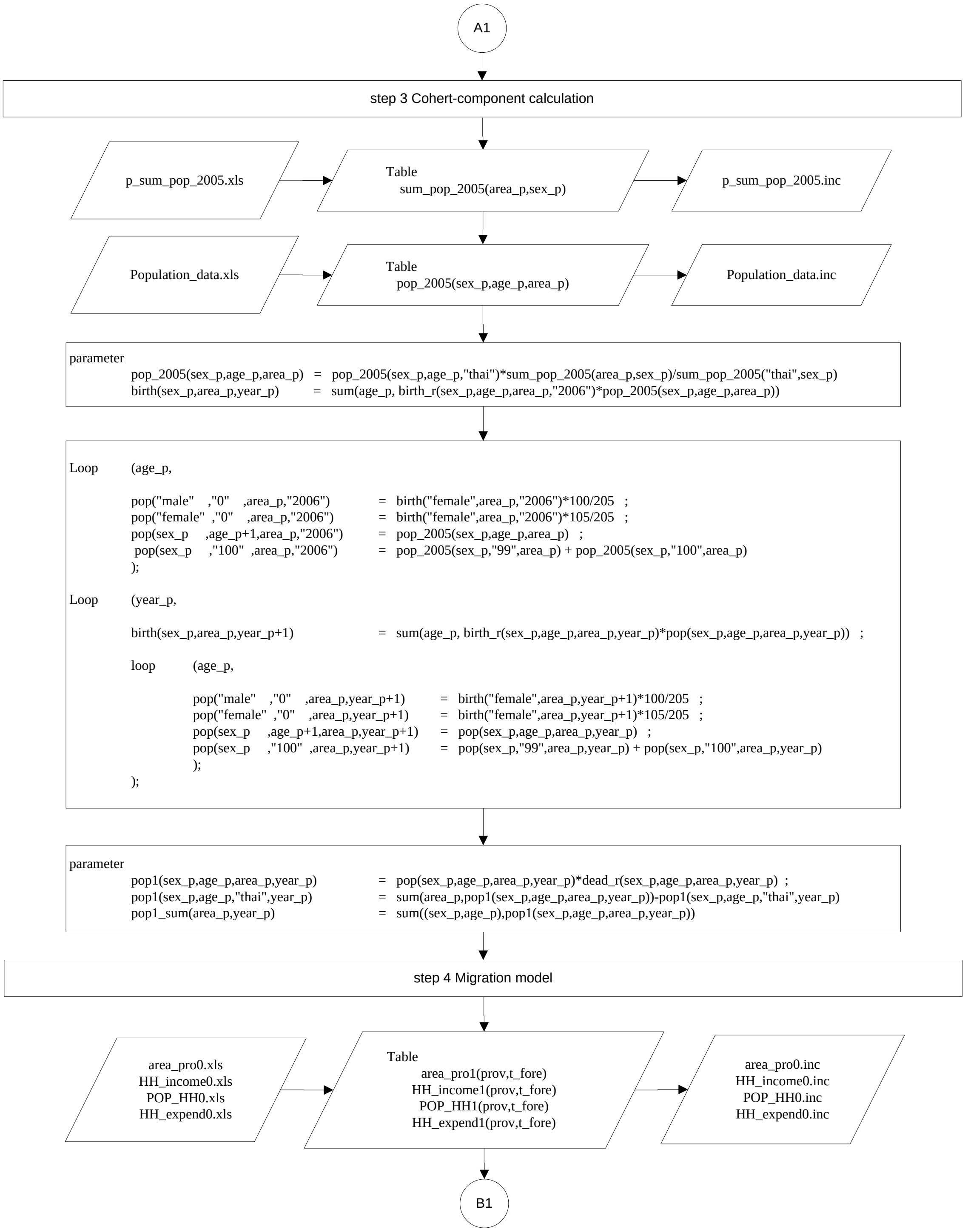
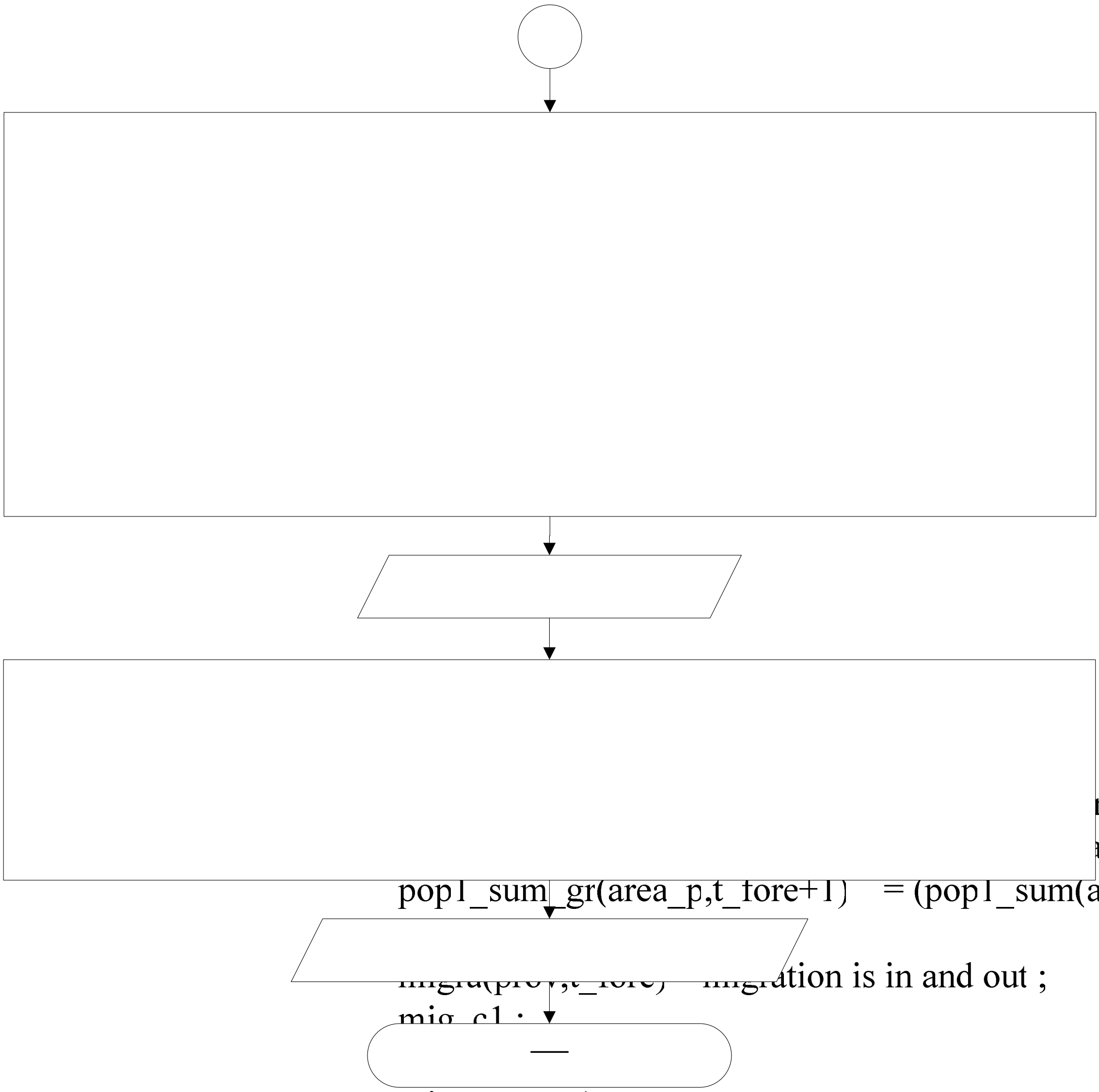


Figure B-1. Schematic diagram of Household water demand management model (Cont’d)



B

n 2005 people
area_p,"2006")-
pop1_sum_gr(area_p,t_fore+1) = (pop1_sum(area_p,t_fore+1)

migra(prov,t_fore) migration is in and out ;
mig_c1 ;

mig_c3(prov) ;
mig_c4(prov) ;
mig_c5(prov) ;

migra("bkk",t_fore) = mig_c1 * pop1_sum_gr("bkk"
mig_c3("bkk") * sum_V0_pro
pop1_sum("bkk",t_fore)) + mi

Figure B-1. Schematic diagram of Household water demand management model (Cont'd)

pop2_sum("BKK",t_fore) = pop1_sum("BKK",t_fore) + m

migra
population_mo

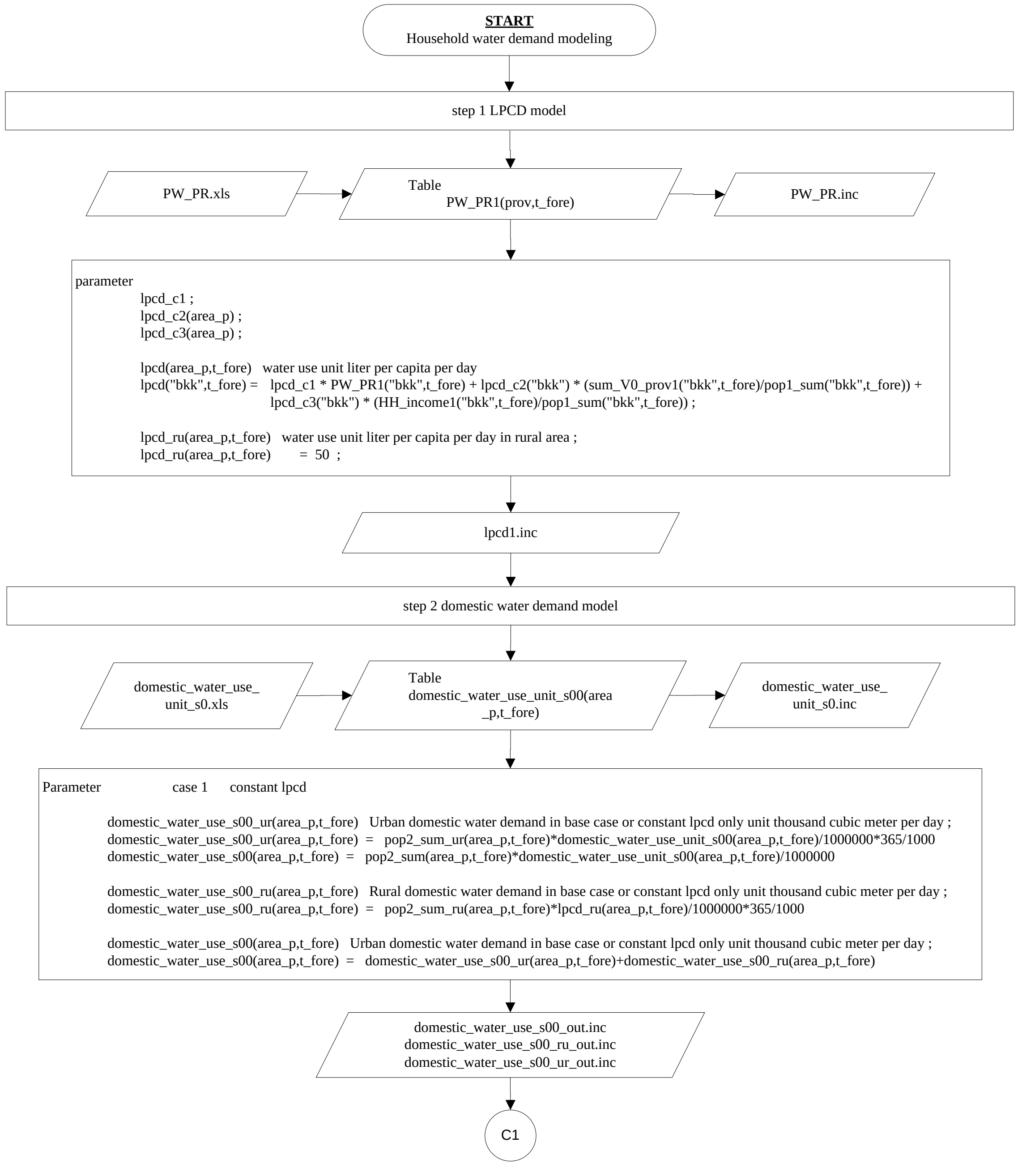


Figure B-1. Schematic diagram of Household water demand management model (Cont’d)

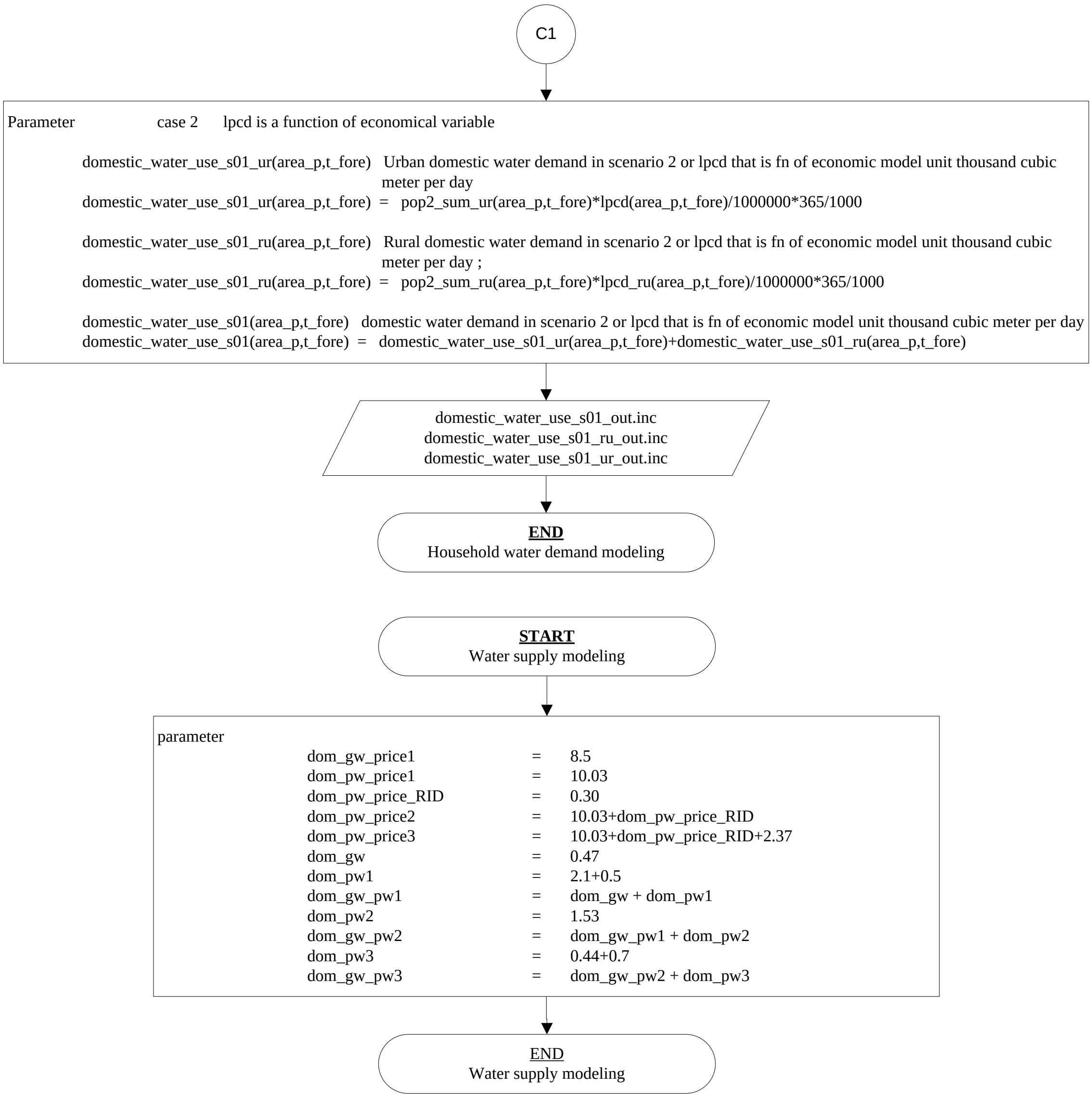


Figure B-1. Schematic diagram of Household water demand management model (Cont’d)

START

Integrated Water management modeling

step 1 Domestic water management model with governmental option

```
case 1     with new water infrastructure but without leakage reduction system

parameters

      a_equation                                              = -20.474     ;
      b_equation                                              = 127.8508    ;

*     case 1   if (supply  <= (GW)) , y =  8.50  baht/ cu.m.

      dom_d_p1                                                = ((dom_gw_price1) - b_equation)  /  (a_equation) ;
      dom_d_p11                                               = 0                ;
      dom_d_p11$(dom_d_p1<=dom_gw)                            = dom_d_p1         ;
      dom_d_p111$(dom_d_p1<=dom_gw)                           = dom_gw_price1    ;

*  case 1_1     if demand curve pass the space between the price 8.50 and 10.03  use = GW  M.cu.m. / d

      dom_d_p1_1                                              = a_equation* dom_gw + b_equation       ;
      dom_d_p11_1$((dom_d_p1_1 > dom_gw_price1)and(dom_d_p1_1 <= dom_pw_price1))     = dom_gw     ;
      dom_d_p111_1$((dom_d_p1_1 > dom_gw_price1)and(dom_d_p1_1 <= dom_pw_price1))    = dom_d_p1_1     ;

*  case 2      if ((GW) < supply <= (GW+PW1))  , y = 10.03  baht/ cu.m.

      dom_d_p2                                                = ((dom_pw_price1) - b_equation)  /  (a_equation) ;
      dom_d_p21$((dom_d_p2 > dom_gw)and(dom_d_p2 <= dom_gw_pw1))        = dom_d_p2        ;
      dom_d_p211$((dom_d_p2 > dom_gw)and(dom_d_p2 <= dom_gw_pw1))       = dom_pw_price1   ;

*  case 2_1     if demand curve pass the space between the price 10.03  and 10.33 use = 3.07  M.cu.m. / d

     dom_d_p2_1                                               = a_equation* dom_gw_pw1 + b_equation       ;
     dom_d_p21_1$((dom_d_p2_1 > dom_pw_price1)and(dom_d_p2_1 <= dom_pw_price2))     = dom_gw_pw1     ;
     dom_d_p211_1$((dom_d_p2_1 > dom_pw_price1)and(dom_d_p2_1 <= dom_pw_price2))    = dom_d_p2_1     ;

*  case 3      if ((GW+PW1)  <  supply ) , y = 10.33  baht/ cu.m.

      dom_d_p3                                                = ((dom_pw_price2) - b_equation)  /  (a_equation) ;
      dom_d_p31$((dom_d_p3 > dom_gw_pw1))                     = dom_d_p3        ;
      dom_d_p311$((dom_d_p3 > dom_gw_pw1))                    = dom_pw_price2     ;

      dom_w_d              =  dom_d_p11 + dom_d_p11_1 + dom_d_p21  + dom_d_p21_1 + dom_d_p31   ;
      dom_w_s              =  dom_w_d  ;
      dom_eq_w_p           =  dom_d_p111 + dom_d_p111_1 + dom_d_p211  + dom_d_p211_1 + dom_d_p311   ;
```

D1

Figure B-1. Schematic diagram of Household water demand management model (Cont'd)

D1

```
case 2     with new water infrastructure and with leakage reduction system

parameters

       a1_equation                                      =  -20.474     ;
       b1_equation                                      =  130.2208     ;


*      case 1   if (supply  <= (GW)) , y =  8.50  baht/ cu.m.

       dom_d1_p1                                        =  ((dom_gw_price1) - b1_equation)  /  (a1_equation) ;
       dom_d1_p11                                       =  0                         ;
       dom_d1_p11$(dom_d1_p1<=dom_gw)                   =  dom_d1_p1                       ;
       dom_d1_p111$(dom_d1_p1<=dom_gw)                  =  dom_gw_price1                    ;

*  case 1_1      if demand curve pass the space between the price 8.50 and 10.03  use = GW  M.cu.m. / d

       dom_d1_p1_1                                      =  a1_equation* dom_gw + b1_equation             ;
       dom_d1_p11_1$((dom_d1_p1_1 > dom_gw_price1)and(dom_d1_p1_1 <= dom_pw_price1))   = dom_gw      ;
       dom_d1_p111_1$((dom_d1_p1_1 > dom_gw_price1)and(dom_d1_p1_1 <= dom_pw_price1)) = dom_d1_p1_1          ;

*  case 2       if ((GW) < supply <= (GW+PW1))  , y = 10.03  baht/ cu.m.

       dom_d1_p2                                        =  ((dom_pw_price1) - b1_equation)  /  (a1_equation) ;
       dom_d1_p21$((dom_d1_p2 > dom_gw)and(dom_d1_p2 <= dom_gw_pw1))                  =  dom_d1_p2             ;
       dom_d1_p211$((dom_d1_p2 > dom_gw)and(dom_d1_p2 <= dom_gw_pw1))                 =  dom_pw_price1         ;

*  case 2_1      if demand curve pass the space between the price 10.03  and 10.33 use = 3.07  M.cu.m. / d

      dom_d1_p2_1                                       =  a1_equation* dom_gw_pw1 + b1_equation             ;
      dom_d1_p21_1$((dom_d1_p2_1 > dom_pw_price1)and(dom_d1_p2_1 <= dom_pw_price2))    = dom_gw_pw1       ;
      dom_d1_p211_1$((dom_d1_p2_1 > dom_pw_price1)and(dom_d1_p2_1 <= dom_pw_price2))  = dom_d1_p2_1       ;

*  case 3       if ((GW+PW1)  <  supply  <= (GW+PW1+PW2)) , y = 10.33  baht/ cu.m.

       dom_d1_p3                                        =  ((dom_pw_price2) - b1_equation)  /  (a1_equation) ;
       dom_d1_p31$((dom_d1_p3 > dom_gw_pw1)and(dom_d1_p3 <= dom_gw_pw2))            =  dom_d1_p3          ;
       dom_d1_p311$((dom_d1_p3 > dom_gw_pw1)and(dom_d1_p3 <= dom_gw_pw2))           =  dom_pw_price2      ;

*  case 3_1      if demand curve pass the space between the price 10.33  and 12.7 use = 4.6  M.cu.m. / d

      dom_d1_p3_1                                       =  a1_equation* dom_gw_pw2 + b1_equation             ;
      dom_d1_p31_1$((dom_d1_p3_1 > dom_pw_price2)and(dom_d1_p3_1 <= dom_pw_price3))    = dom_gw_pw2       ;
      dom_d1_p311_1$((dom_d1_p3_1 > dom_pw_price2)and(dom_d1_p3_1 <= dom_pw_price3))  = dom_d1_p3_1       ;

*  case 4       if ((GW+PW1+PW2)     <  supply  )              , y = 12.70  baht/ cu.m.

       dom_d1_p4                                        =  ((dom_pw_price3) - b1_equation)  /  (a1_equation) ;
       dom_d1_p41$(dom_d1_p4 > dom_gw_pw2)              =  dom_d1_p4             ;
       dom_d1_p411$(dom_d1_p4 > dom_gw_pw2)             =  dom_pw_price3         ;

       dom_w1_d          =  dom_d1_p11 + dom_d1_p11_1 + dom_d1_p21  + dom_d1_p21_1 + dom_d1_p31 + dom_d1_p31_1 + dom_d1_p41  ;
       dom_w1_s          =  dom_w1_d  ;
       dom_eq_w1_p       =  dom_d1_p111 + dom_d1_p111_1 + dom_d1_p211  + dom_d1_p211_1 + dom_d1_p311 + dom_d1_p311_1 +
                            dom_d1_p411  ;
```

E1

Figure B-1. Schematic diagram of Household water demand management model (Cont'd)

E1

Option

governmental option scenarios

1 without leakage reduction system
2 with leakage reduction system without subsidy from governemntal side
3 with leakage reduction system with subsidy from governemntal side
4 is case 1.3 but the question is what price that leakage reduction system will be suitable to invest
nowaday, the cost of raw water to produce pipe water is very cheap 0.30 THB in the mekong and tha chin river
RID will sell water to WA if the river get water from irrigation dam

governmental option scenarios case 1-3

```
Set
        dom_gov_case   =   1*3      (1=case1、2＝case2,3=case3)
```

```
parameter
            D_B_w_sale(dom_gov_case)          = 0 ;
            D_B_con_sur(dom_gov_case)         = 0 ;
            D_B_pro_sur(dom_gov_case)         = 0 ;
            D_B_free_w(dom_gov_case)          = 0 ;
            D_B_Total(dom_gov_case)           = 0 ;
            D_C_leak_con(dom_gov_case)        = 0 ;
            D_C_subsidy(dom_gov_case)         = 0 ;
            D_C_total(dom_gov_case)           = 0 ;
            D_B_NET(dom_gov_case)             = 0 ;
```

```
Parameter

*       domestic benefit from selling water

        D_B_w_sale("1")     =   dom_pw_price2*((dom_pw_price2) - b_equation)  /  (a_equation) ;
        D_B_w_sale("2")     =   dom_pw_price3*((dom_pw_price3) - b_equation)  /  (a_equation) ;
        D_B_w_sale("3")     =   dom_pw_price2*((dom_pw_price2) - b_equation)  /  (a_equation) ;

*       domestic benefit from comsumer surplus

        D_B_con_sur("1")    =   0.5*(b_equation-dom_pw_price2)*((dom_pw_price2) - b_equation)  /  (a_equation) ;
        D_B_con_sur("2")    =   0.5*(b_equation-dom_pw_price3)*((dom_pw_price3) - b_equation)  /  (a_equation) ;
        D_B_con_sur("3")    =   0.5*(b_equation-dom_pw_price2)*((dom_pw_price2) - b_equation)  /  (a_equation) ;

*       domestic benefit from producer surplus

        D_B_pro_sur("1")    =   dom_gw*(dom_pw_price2-dom_gw_price1)+(dom_gw_pw1-dom_gw)*(dom_pw_price2-
                                dom_pw_price1)+(dom_gw_pw2-dom_gw_pw1)*(dom_pw_price2-dom_pw_price2) ;
        D_B_pro_sur("2")    =   dom_gw*(dom_pw_price3-dom_gw_price1)+(dom_gw_pw1-dom_gw)*(dom_pw_price3-
                                dom_pw_price1)+(dom_gw_pw2-dom_gw_pw1)*(dom_pw_price3-dom_pw_price2)+ ((((dom_pw_price3) -
                                b_equation)  /  (a_equation))-dom_gw_pw2)*(dom_pw_price3-dom_pw_price3);
        D_B_pro_sur("3")    =   dom_gw*(dom_pw_price2-dom_gw_price1)+(dom_gw_pw1-dom_gw)*(dom_pw_price2-
                                dom_pw_price1)+(dom_gw_pw2-dom_gw_pw1)*(dom_pw_price2-dom_pw_price2) ;

*       domestic benefit from getting free water from leakage reduction

        D_B_free_w("2")     =   (((dom_pw_price3-b_equation)/(a_equation))-dom_gw_pw2)*dom_pw_price_RID ;
        D_B_free_w("3")     =   (((dom_pw_price2-b_equation)/(a_equation))-dom_gw_pw2)*dom_pw_price_RID ;

*       total domestic benefit

        D_B_Total(dom_gov_case) =   D_B_w_sale(dom_gov_case)+ D_B_con_sur(dom_gov_case) + D_B_pro_sur(dom_gov_case) +
                                    D_B_free_w(dom_gov_case) ;
```

F1

Figure B-1. Schematic diagram of Household water demand management model (Cont’d)

F1

```
Parameter

*       domestic benefit from selling water

        D_B_w_sale("1")          =     dom_pw_price2*((dom_pw_price2) - b_equation)  /  (a_equation) ;
        D_B_w_sale("2")          =     dom_pw_price3*((dom_pw_price3) - b_equation)  /  (a_equation) ;
        D_B_w_sale("3")          =     dom_pw_price2*((dom_pw_price2) - b_equation)  /  (a_equation) ;

*   cost calculation

*       domestic cost from leackage construction cost

        D_C_leak_con("2")        =     (((dom_pw_price3-b_equation)/(a_equation))-dom_gw_pw2)*(dom_pw_price3-dom_pw_price2) ;
        D_C_leak_con("3")        =     (((dom_pw_price2-b_equation)/(a_equation))-dom_gw_pw2)*(dom_pw_price3-dom_pw_price2) ;

*       domestic cost from governmental subsidy

        D_C_subsidy("3")         =     (((dom_pw_price2-b_equation)/(a_equation))-dom_gw_pw2)*(dom_pw_price3-dom_pw_price2) ;

*       total domestic cost

        D_C_total(dom_gov_case)  =     D_C_leak_con(dom_gov_case)+D_C_subsidy(dom_gov_case) ;

*   net benefit calculation
*       net benefit for domestic sector

        D_B_NET(dom_gov_case)    =     D_B_Total(dom_gov_case) - D_C_total(dom_gov_case) ;
```

governmental option scenarios case 4

```
VARIABLES

      dom_pw_price_RID1        analyzed unit price of raw water bought from RID that is bought from RID THB per cu.m.
      diff_dom1                difference between net benefit of case 1.1 and 1.4
```

```
EQUATIONS

      OBJ_diff_dom1            Objective function in case 1.4 ;

OBJ_diff_dom1.. diff_dom1   =E=   D_B_NET("1")
                                  -  (dom_gw_pw3*(dom_pw_price1+dom_pw_price_rid1)
                                     +0.5*(b_equation-.3+dom_pw_price_rid1-(10.03+dom_pw_price_rid1))*(dom_gw_pw3)
                                     +dom_gw*(dom_pw_price1+dom_pw_price_rid1-dom_gw_price1)+dom_pw1*dom_pw_price_rid1
                                     +dom_pw3*dom_pw_price_rid1
                                     -2.37*dom_pw3
                                     -(2.37+dom_pw_price_rid1)*dom_pw3
                                    ) ;
diff_dom1.lo=0;
diff_dom1.up=0;
```

```
MODEL          diff_dom_m1   /  OBJ_diff_dom1  /  ;

OPTIONS ITERLIM=10000,LIMROW=0,LIMCOL=0,SOLPRINT=OFF ;
option  nlp=minos;
```

```
SOLVE          diff_dom_m1 USING NLP MINIMIZING diff_dom1 ;
```

G1

Figure B-1. Schematic diagram of Household water demand management model (Cont’d)

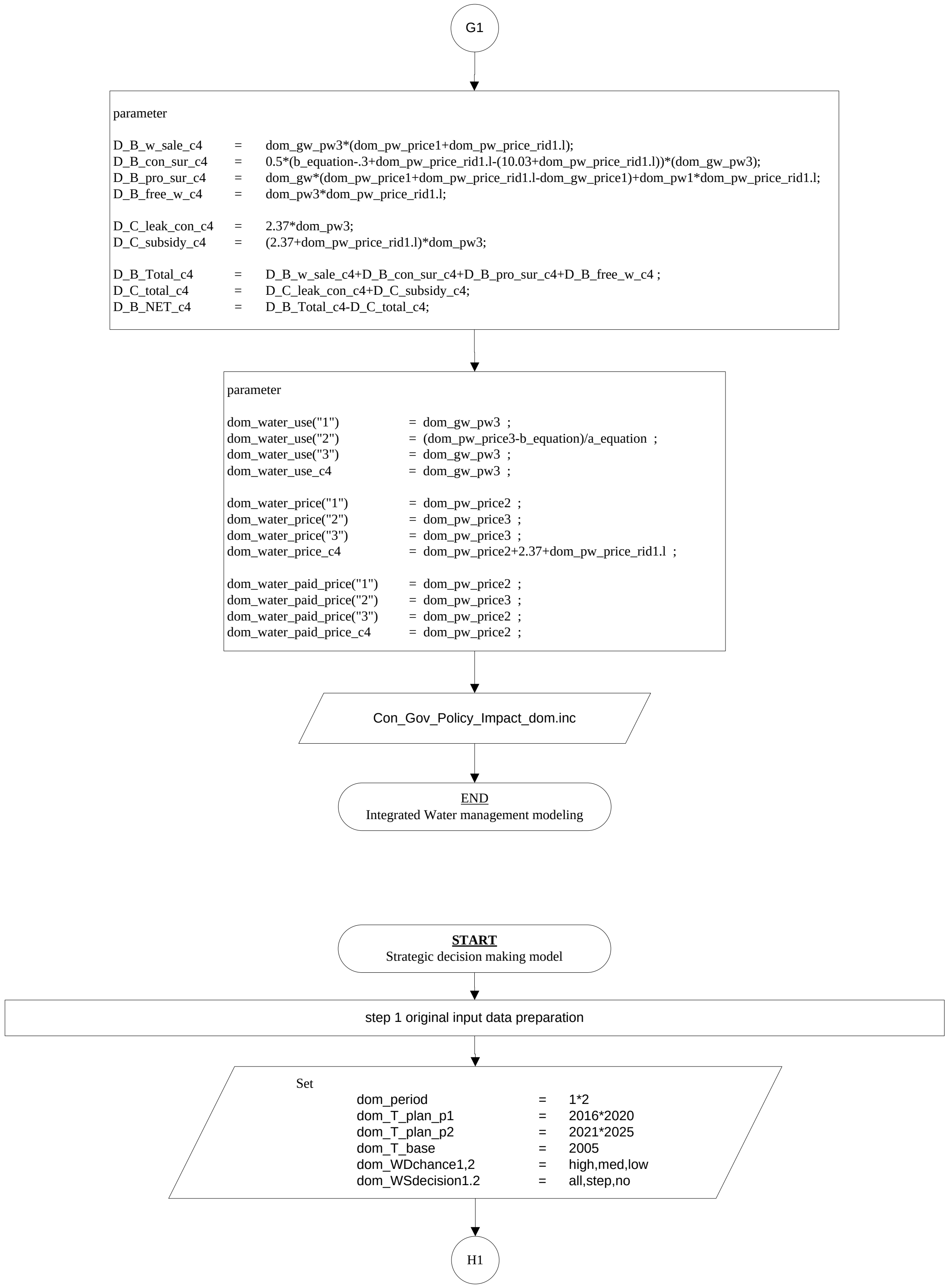


Figure B-1. Schematic diagram of Household water demand management model (Cont'd)

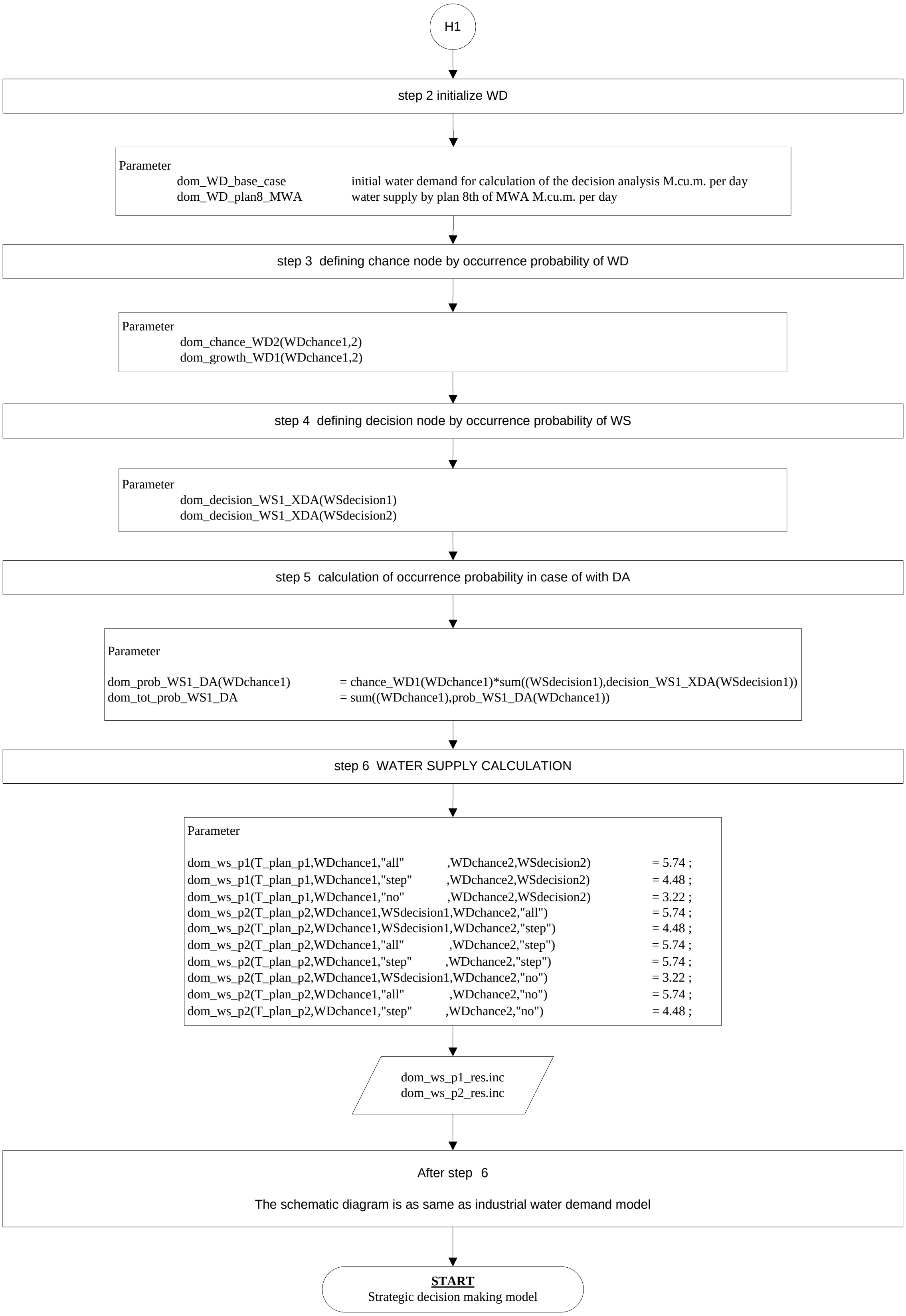


Figure B-1. Schematic diagram of Household water demand management model (Cont'd)

Appendix C

Schematic diagram in details

Agricultural sector

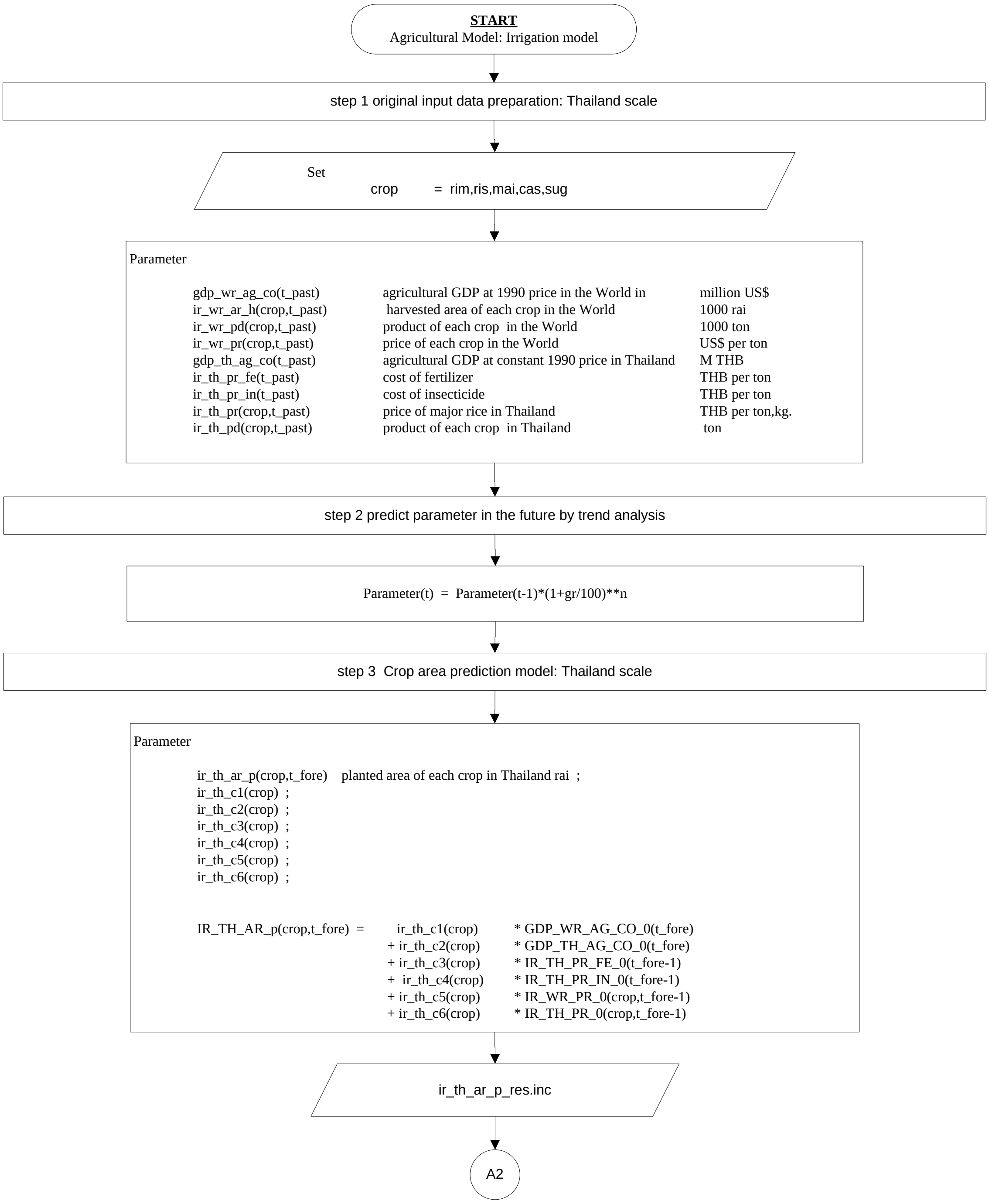


Figure C-1. Schematic diagram of Agricultural water demand management model (Cont'd)

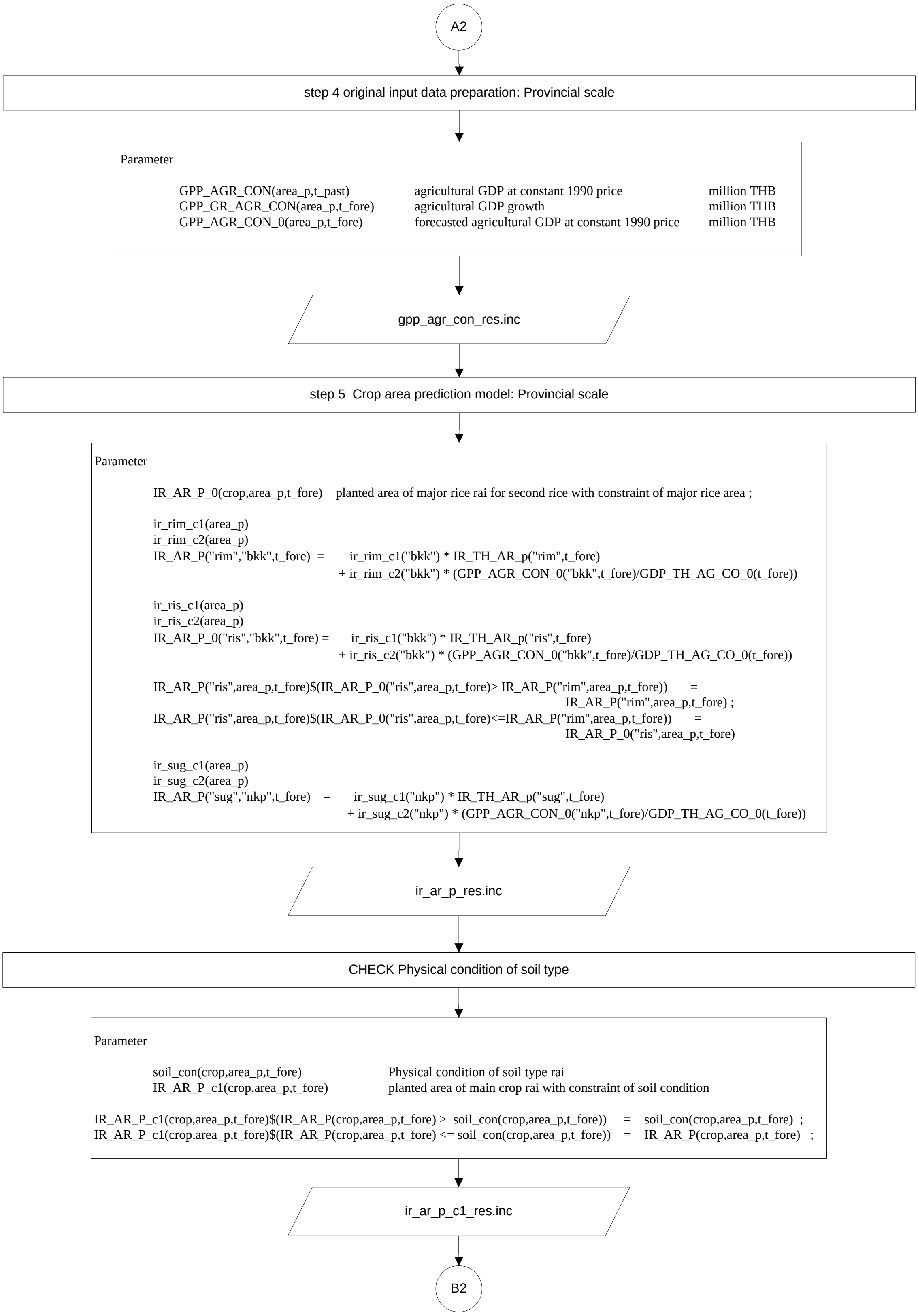


Figure C-1. Schematic diagram of Agricultural water demand management model (Cont’d)

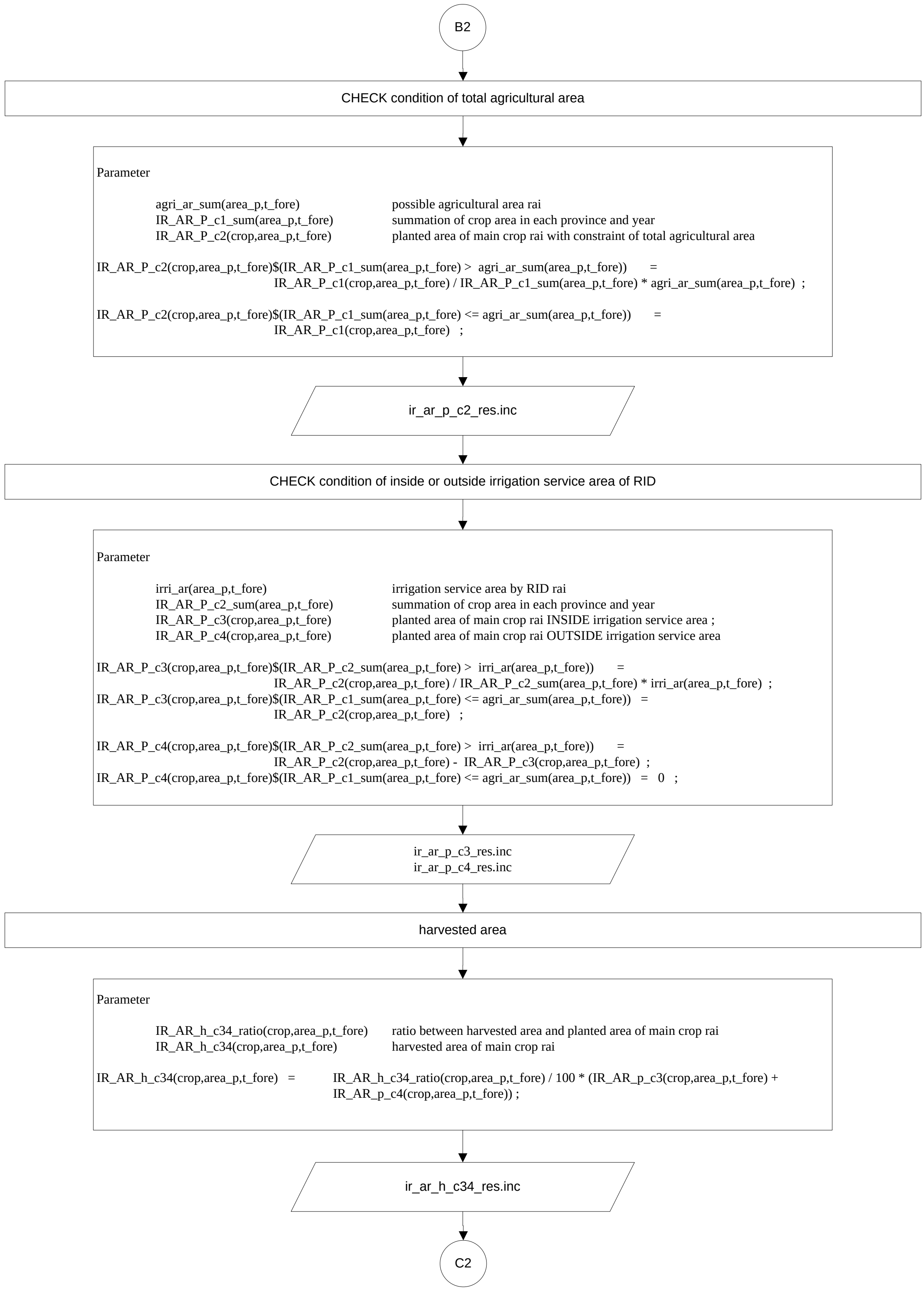


Figure C-1. Schematic diagram of Agricultural water demand management model (Cont'd)

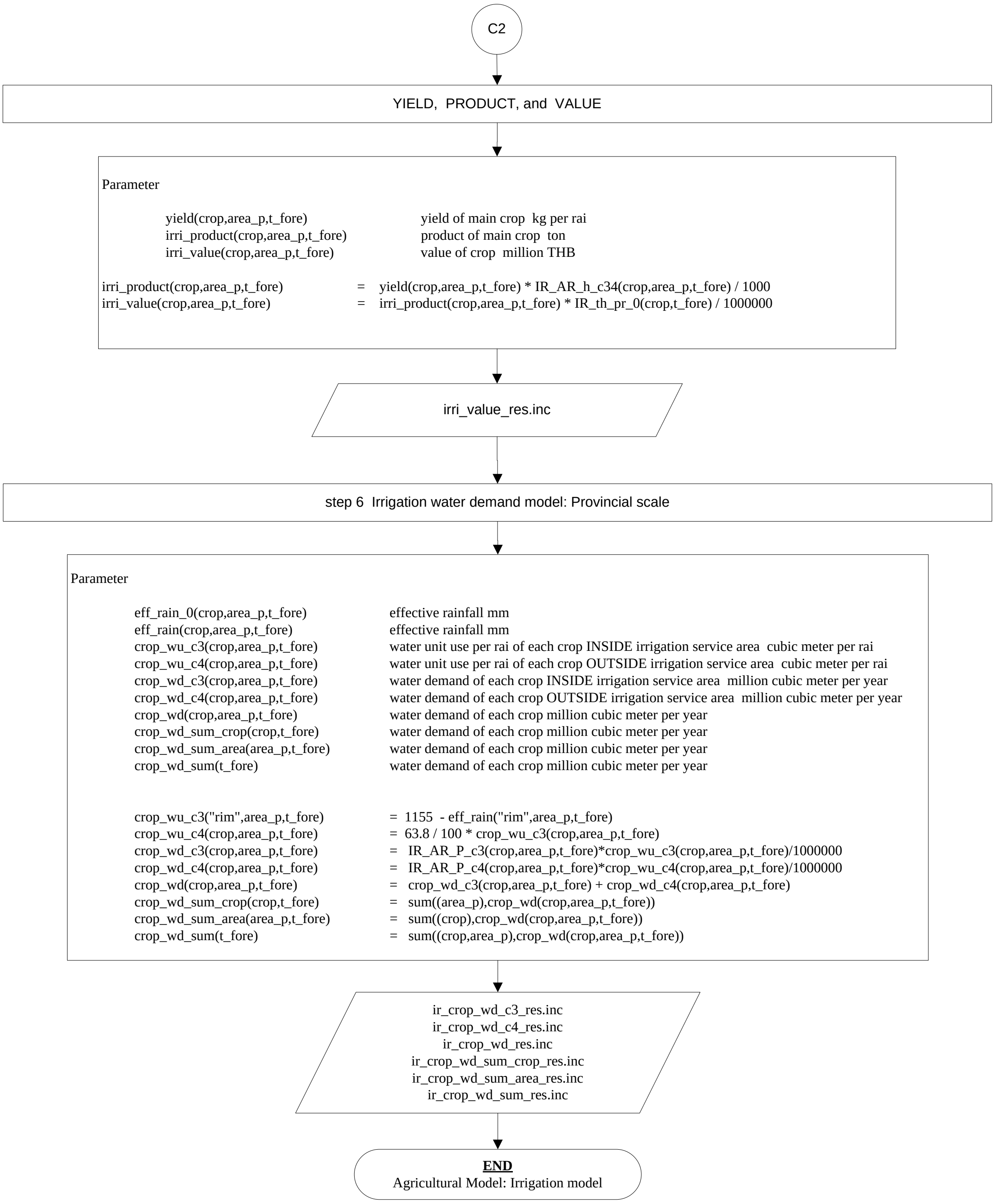


Figure C-1. Schematic diagram of Agricultural water demand management model (Cont’d)

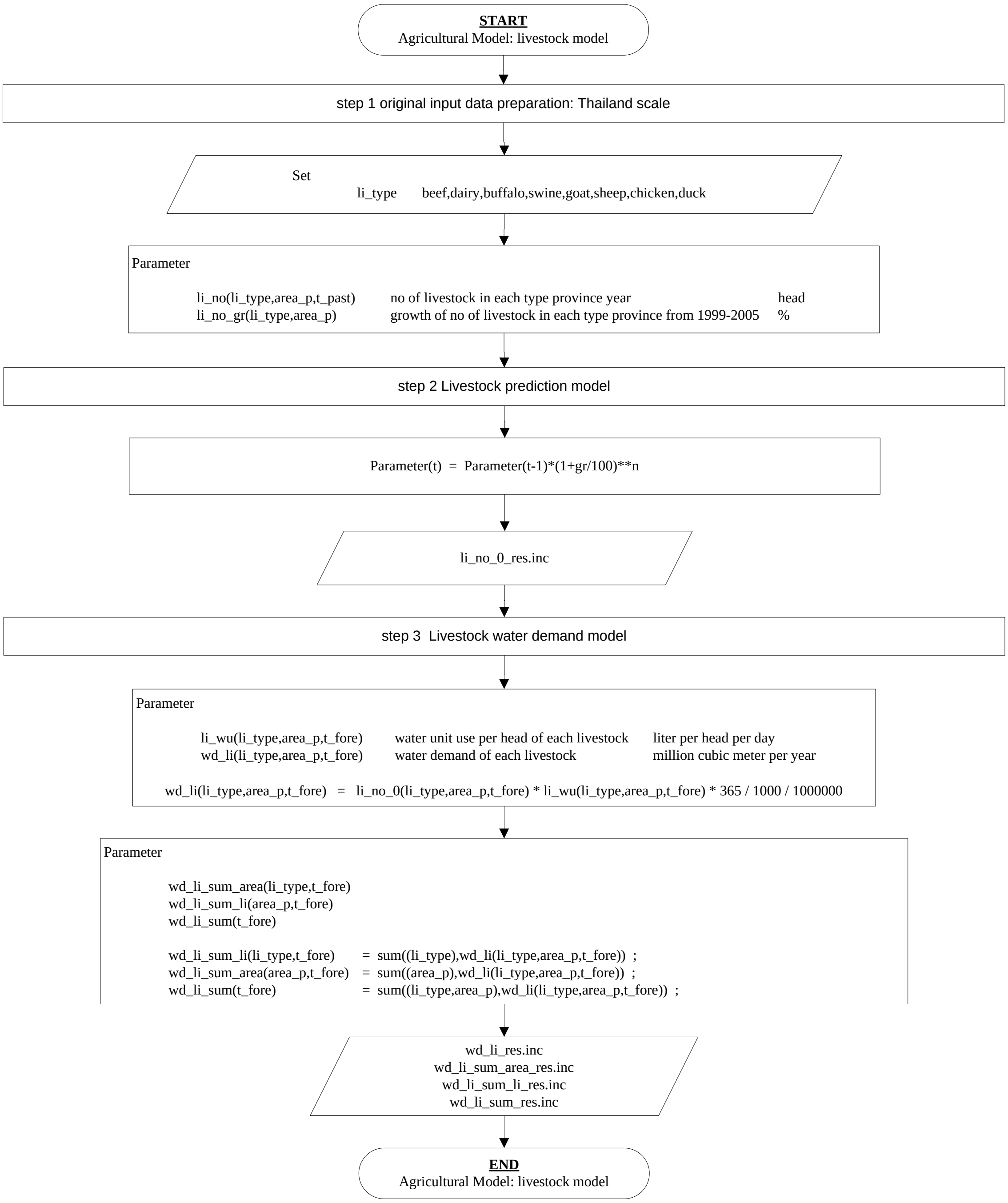
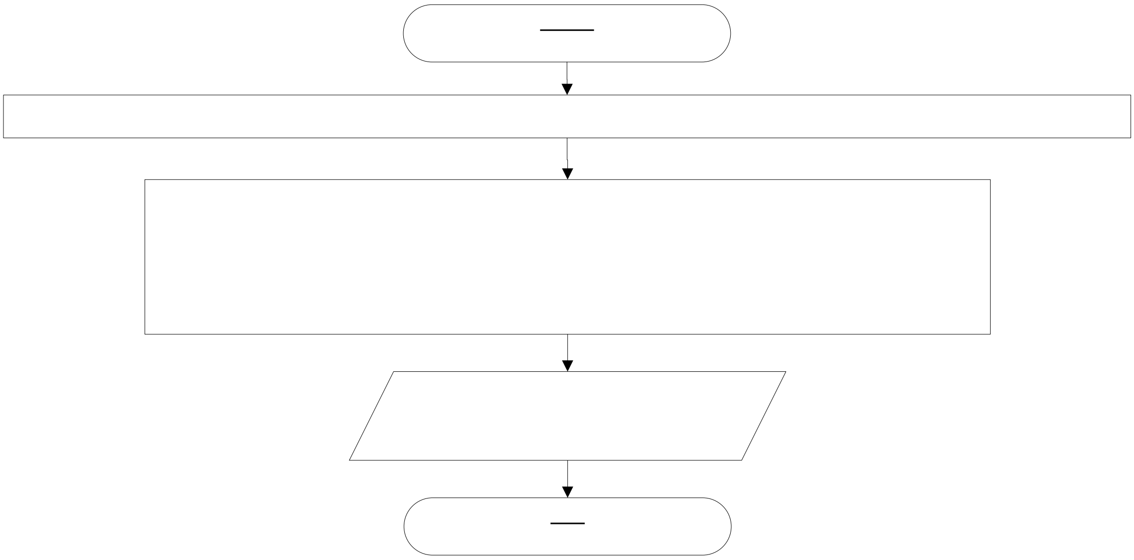


Figure C-1. Schematic diagram of Agricultural water demand management model (Cont'd)



STA

Agricultu

summation of irrigation m

Parameter

agri_wd_sum_area(area_p,t_fore) agricultu
agri_wd_sum(t_fore) agricultu

agri_wd_sum_area(area_p,t_fore) = crop_
agri_wd_sum(t_fore) = crop_

Figure C-1. Schematic diagram of Agricultural water demand management model – (Cont'd)

Appendix D

Questionnaire samples

Industrial sector

Household sector

Questionaire for industrial sector

Research Topic: Water Demand Forecasting and Management in The Lower Chao Phraya River Basin

Kochi University of Technology
Kochi, Japan

- Factory code: •Factory name:
- Industrial type: •Address: • Tel
- Monthly output: Million Baht •Officer name: • Position • Fax

1. Water use and source

Water source	Water use (m^3/month)		Water price (B/m^3)		initial cost	Problem and Solution [1]
	Average	Max	Now	Suitable	to invest	Note 1
Tap water						
Groundwater						
surface water ☐ Pond						
☐ River						
☐ Natural canal ☐ Irrigation canal						
other						
Total use						

2. Water use in factory

process	activity	water use in each source (m^3/month)					water type [2]
		Tap water	Groundwater	surface water	....	....	Note 2
Production process	1.1 Input						
	1.2 Washing						
	1.3						
	1.4						
	total						
Utility process	2.1 Boiler						
	2.2 Cooling system						
	2.3						
	2.4						
	total						
Others	3.1 Office						
	3.2 Dormitory						
	3.2						
	3.4						
	total						

3. Water sitauation in the present and future

3.1 Is the factory located in the service area of waterworks authority? ☐ Yes ☐ No

3.2 Does pipe water effect to the production process? (Ex. Chlorine problem) ☐ Yes ☐ No

How? ....

3.3 Do you have water saving policy in your factory? ☐ Yes ☐ No

- ☐ Recycling water ratio ....% unit cost ....
- ☐ Using treated raw water ratio ....% unit cost ....
- ☐ Saving the production water ratio ....% unit cost ....
- ☐ Other .... ratio ....% unit cost ....

3.4 At what price, do you think you will use tap water? ....

At what price, do you think you will use tap water with no chlorine? ....

3.5 How does your water use change in this condition?

If-condition	Activity in topic 2 Ex. 1.1,3.4,...
Tap water service available	
Tap water price = price in 3.4	

3.6 Trend of water use and source in the next 5 years

- ☐ Tap water increase,decrease .....% ☐ SW increase,decrease .....%
- ☐ GW increase,decrease .....% ☐ .... increase,decrease .....%

3.7 Are you intertested in water saving policy in your factory in the future? ☐ Yes ☐ No

(please put the rank in the box; 1= the best)

- ☐ Recycling water ☐ Saving the production water
- ☐ Using treated raw water ☐ Industrial water by government
- ☐ Other ....

Note

1 Example of Problems; no water, high price, water quality, unstable supply, etc.
Example of solutions; other water source, treatment process, etc.

2 T1 = Raw water, T2 = Sand filter, T3 = Softed water, T4 = Demineralized water, T5 = RO water, T6 = UV water, T7 = Activated water, T8 = other ....

[Contact] Ms. Wanwaree Wongkasemsun, Water Resources System Research Unit, R. 203 Building 2, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand, 10330, tel: 0-2218-6126 Fax: 0-2218-6425, email: waterCU@eng.chula.ac.th

Questionaire for household sector

KUT_HH_02

Research Topic: Water Demand Forecasting and Management in The Lower Chao Phraya River Basin

Kochi University of Technology
Kochi, Japan

- Address: Road: Tumbon: Amphoe: Province:
- Family: number of men people number of women people

1. Water use and source

Water source		Water use, cost (m^3/month,B)		Water price (B/m^3)		*Problem and Solution* [1]
		Average	Max	Now	Suitable	*Note 1*
Tap water						
Groundwater						
surface water	☐ Pond					
	☐ River					
☐ Natural canal	☐ Irrigation canal					
other						
Total use						

2. Water use in house

process	Activity	person	water use in each source and how often; per day, week				Facility
			Tap water	Ground water	Surface water	other	
1. Bathroom	1.1 Shower		☐	☐	☐	☐	
	1.2 Bathtub		☐	☐	☐	☐	
	1.3 Using bowl		☐	☐	☐	☐	
2. Toilet	2.1 Flush		☐	☐	☐	☐	
	2.2 Squat		☐	☐	☐	☐	
3. laundry	3.1 Machine	-	☐	☐	☐	☐	size of washing machine
	3.2 Manual	-	☐	☐	☐	☐	
4. Cleaning	4.1 Car	-	☐	☐	☐	☐	no of car
	4.2 Home	-	☐	☐	☐	☐	no of room
5. Garden	5.1 Sprinkle	-	☐	☐	☐	☐	size of garden
	5.2 Manual	-	☐	☐	☐	☐	duration
6. Kitchen	6.1 Dish washing		☐	☐	☐	☐	no of meal
	6.2 Cooking		☐	☐	☐	☐	

Note 1 Example of Problems; no water, high price, water quality, unstable supply, etc.
Example of solutions; other water source, treatment process, etc.

3. Water situation in the present and future

3.1 Is your house located in the service area of waterworks authority? ☐ Yes ☐ No

3.2 What is the change of water use in your house? (Ex. 2.2 Squat, past = canal, now = pipe water)

activity in topic 2	water source			Note
	past	present	future	

3.3 Why do you choose tap water? (in case of using tap water)

☐ Better quality than the others ☐ Stable discharge
☐ Only tap water ☐ Service from government
☐ Better quality of life and profit ☐ More comfortable life
☐ Other ....

3.4 At what price, do you think you will use tap water? ....

How much does your water use change in this condition?

If-condition	Activity in topic 2 Ex. 1.1,3.4,...
Tap water service available	
Tap water price = price in 3.4	

3.5 Are you intertested in water saving policy in your house in the future? ☐ Yes ☐ No

(please put the rank in the box; 1= the best)

☐ Save water, save cost project by government ☐ Water saving plug or equipment
☐ Less water use facility ☐ Other ....

4. Suggestion

....
....
....
....
....

[Contact] Ms. Wanwaree Wongkasemsun, Water Resources System Research Unit, R. 203 Building 2, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand, 10330, tel: 0-2218-6126 Fax: 0-2218-6425, email: waterCU@eng.chula.ac.th

Appendix E

Recommendations from meeting with Thai Government agencies Bangkok, Thailand 20-25 August 2007

Objectivs

Present and discuss about the progress of research and the next plan with related government agencies in responsibilities of policy makers, water supply, water user, and academic side.

Target: 9 Government agencies

1. Policy makers' side
   - National Economic and Social Development Board (NESDB)
   - Office of Industrial Economics (OIE)
   - Department of Industrial, Industrial Water Technology Institute (IWTI)

2. Water supply side
   - Department of Water Resources (DWR) (cancelled)
   - Metropolitan Waterworks Authority (MWA)
   - Department of Groundwater Resources (DGR)

3. Water user side
   - Industrial Estate Authority of Thailand (IEAT)
   - The Federation of Thai Industries (FTI)

4. Academic side
   - Chulalongkorn University (CU)

Discussions and recommendations

Agencies: **Water Resources System Research Unit, Department of Water Resources Engineering, Chulalongkorn University**

Date and time: 1st day: 20th August 2007, 09.00-12.20

Audiences: Mr. Chaiyuth Sukhsri *(Head of department)*
Assoc. Prof. Sucharit Koontanakulvong *(Head of research unit)*
Officers of Water Resources System Research Unit
Master students of Chulalongkorn University
Master students of Shibaura Institute of Technology

Discussion topics:

1. Because this model is the first version, the assumptions used in this model should be defined clearly for the next update and implementation process.
2. The pricing policy is a powerful tool for management water demand but one important topic is competitiveness of industrial sector with other countries.
3. From the above topic, water users in industrial and domestic sector are sensitive with the higher price of water. In developing countries, the income per capita is not so high, is it possible to use pricing policy?

Agencies: **Office of Industrial Economics (OIE)**

Date and time: 2^{nd} day: 21^{st} August 2007, 11.00-12.00

Audiences: Ms. Ubonwan Lodngeun *(Department of Policy and Planning Analysis)*

Discussion topics:

1. The main problem for industrial sector is awareness of water use in Small and Medium Enterprises (SMEs). These consumers need less water per user but there are numerous numbers of enterprises. These SMEs is scattered in study area and difficultly controlled. The problem is how to promote awareness of water use. Big factory thinks water is a kind of cost but it is not the cost for SMEs' thinking.
2. Thai government has some policy to support water saving policy such as Thailand Board of Investment or BOI has policy to reduce import tax for machine in factory, and etc.
3. For studying of impacts from Free Trade Agreements or FTAs in model, policy makers should consider that FTAs may result to higher benefit but getting loss from environmental sector.
4. Case of water shortage in eastern area of Thailand in 2005 is one of interesting cases about the shortage of industrial water with urgent solutions.
5. Now OIE has a project named "Green Ad Plan" is about water saving policy with waste water management.
6. Effective industrial water use should be concentrated in textile sector.
7. Energy and water are always been saved in the same trend.

Agencies: **Department of Industrial, Industrial Water Technology Institute (IWTI)**

Date and time: 2^{nd} day: 21^{st} August 2007, 14.00-15.00

Audiences: Director and officers 10 peoples

Discussion topics:

1. Now there is no tool that can forecast water demand with impacts from declared governmental policy. IWTI interested in this toolbox because they plan to forecast industrial water demand not only this study area, but also in national scale in next fiscal year. It is possible that this toolbox will be implemented and forecasted in that project with cooperative from Chulalongkorn University.

Agencies: **Department of Groundwater Resources (DGR)**

Date and time: 3^{rd} day: 22^{nd} August 2007, 09.30-10.30

Audiences: Ms. Somkid Buapeng *(Director General of Department)*

Discussion topics:

1. She advised that the name of study area should be reconsidered because Lower Chao Phraya River Basin is always meant the area below Chainat province. She recommended the name of "Bangkok and Vicinities"
2. From the queen's vision, water was concentrated as the national concentrated topic. Department of Groundwater Resources (DGR), Department of Water Resources (DWR), Royal Irrigation Department (RID), and Waterworks Authority (MWA&PWA)are the main parts of water supply side. However, each agency plan and manage water separately. Form this reason; the conjunctive use of all water from each source is not highly effective.
3. It should be concentrated in environmental topic such as salt intrusion, wet land, and etc.
4. Water demand forecasting system with impacts of economics is very interesting for planning step in national and regional scale. Nowadays, the target of national and regional economics is not considered with the constraints of water in each source. Without considering this topic, the water shortage will be occurred like the situation of eastern area of Thailand in the future.

5. The upper limit of groundwater use is using groundwater to the yield point in study area.

Agencies: **Metropolitan Waterworks Authority (MWA)**

Date and time: 3rd day: 22nd August 2007, 13.00-14.00

Audiences: Mr. Seranee Kiettisalpipop *(Director of Investment Planning Division)*
Mr. Nattawut Sanunnuayphon *(Planning Engineer)*

Discussion topics:

1. Now the water leakage in service area is approximately 30 %. MWA would like to keep this rate in the future because of high cost of leakage reduction system compared with cheap unit water cost of raw water bought from RID. However, MWA have willingness to invest if they have some subsidy from central government.
2. The main sources of raw water produced pipe water are 2 sources as follow;
   - Chao Phraya River: 60 cubic meters per second with free of charge because of the law.
   - Mae Klong River: 45 cubic meters per second with cost of 0.50 Thai Baht per cubic meter.
3. The future plans are more pipe water production in plan 8, 9, and 10
   - The 8th plan: Bank-kaen station $4*10^5$ m^3/d. and Mahasawat station $4*10^5$ m^3/d.
   - The 9th plan: Mahasawat station $4*10^5$ m^3/d.
   - The 10th plan: Bank-kaen station $4*10^5$ m^3/d.
4. In recent years, pipe water use was suddenly increasing because of groundwater ban law in study area. This shows the effectiveness of using laws and regulations policy.

Agencies: **The Federation of Thai Industries (FTI)**

Date and time: 4th day: 23rd August 2007, 09.30-10.30

Audiences: Mr. Charn Saralertsophon *(Executive Director)*

Discussion topics:

1. FTI agreed that water is one main factor for development in economics activities.
2. He recommended that the model should consider the detail of each water types in production such as; raw water, sand filter, softed water, demineralized water, and etc.
3. He suggested those ethanol and textiles factories are high water consumers.
4. He said that the industrial cluster will change to geographic cluster.
5. The main important policy should mainly be education and awareness in water users.

Agencies: **Industrial Estate Authority of Thailand (IEAT)**

Date and time: 4th day: 23rd August 2007, 13.00-14.00

Audiences: Ms. Kasemsri Homchean *(Deputy Governor (Operation 1))*
Ms. Srivanik Hasdin *(Director of Industrial Estate Administration Department)*
And officers 3 peoples

Discussion topics:

1. The water shortage in eastern part of Thailand is one of interesting example in Thailand.
2. The interesting topic is how to manage water use among each type of user with limitation of water. Now the problem tends to be social problem such as the conflict in each group.
3. IEAT manages water use in service area by using these measures as follow;
   - Finding new source such as new pond in estate.
   - Recycles water: average rate is 22 %.
4. The characteristics of water using time between domestic and industrial sector is different. Industrial sector needs water 24 hours per day with constant pressure. If MWA can recommend the quantity and pressure, the factory will have willingness to use pipe water in all process.
5. IEAT recommended education and awareness policy to water users.
6. The water cost in IEAT is 19-20 Thai Baht per m^3.

Agencies: **National Economic and Social Development Board (NESDB)**

Date and time: 4th day: 23rd August 2007, 16.30-18.00

Audiences: Dr. Potchana Auengpaibul *(Director of Water Resources Planning Sector)*
And officer 1 people

Discussion topics:

1. For pricing policy, one of interesting measure is additional cost from recycled or treatment process.
2. In process of water share among each user, the subsidy and shared benefit should be carefully considered because of social problem.
3. NESDB is interested in this toolbox because of now water demand forecasting system was analyzed by officers in each government agency. It takes much time and budget. If this model is successful, water demand can be managed under impacts of declared policy and constraints of water in study area.

Appendix F

Recycled rate of water in each ISIC code of Japan

(Source: http://www.stat.go.jp, http://www.meti.go.jp)

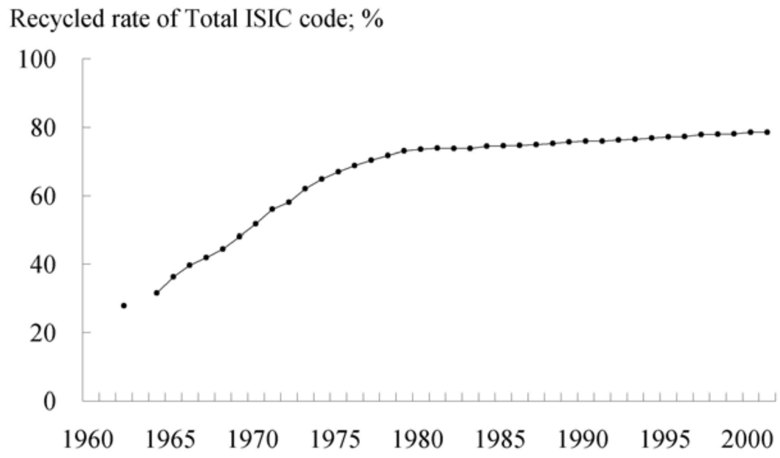


Figure F-1. Recycled water rate in average ISIC code of Japan

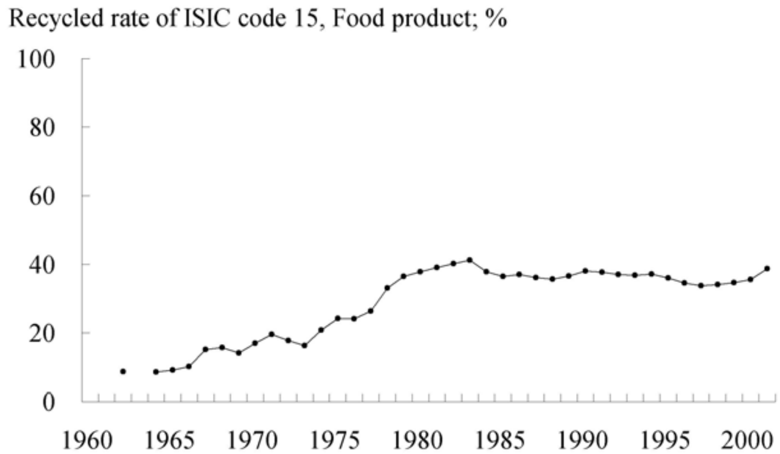


Figure F-2. Recycled water rate in ISIC code 15- food product of Japan

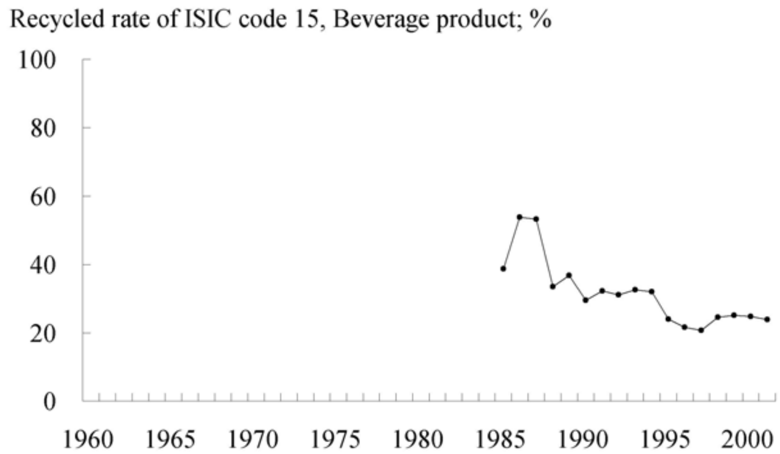


Figure F-3. Recycled water rate in ISIC code 15- beverage product of Japan

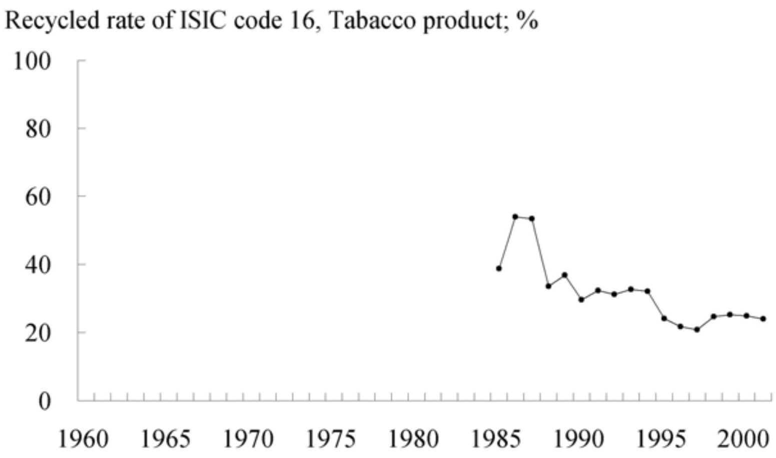


Figure F-4. Recycled water rate in ISIC code 16 of Japan

Figure F-5. Recycled water rate in ISIC code 17 of Japan

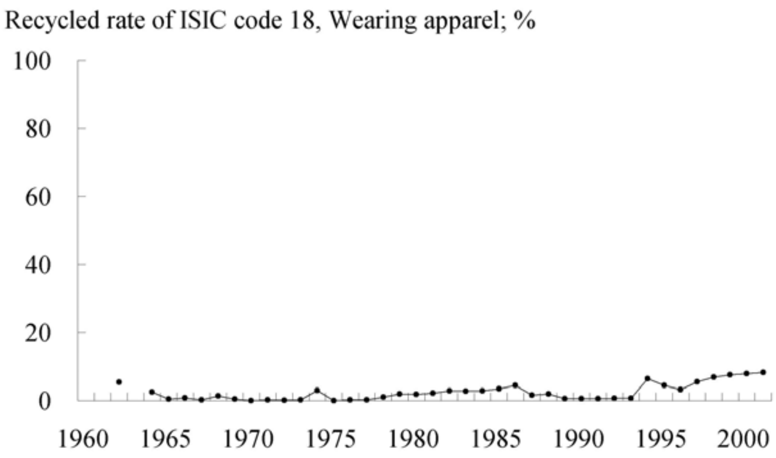


Figure F-6. Recycled water rate in ISIC code 18 of Japan

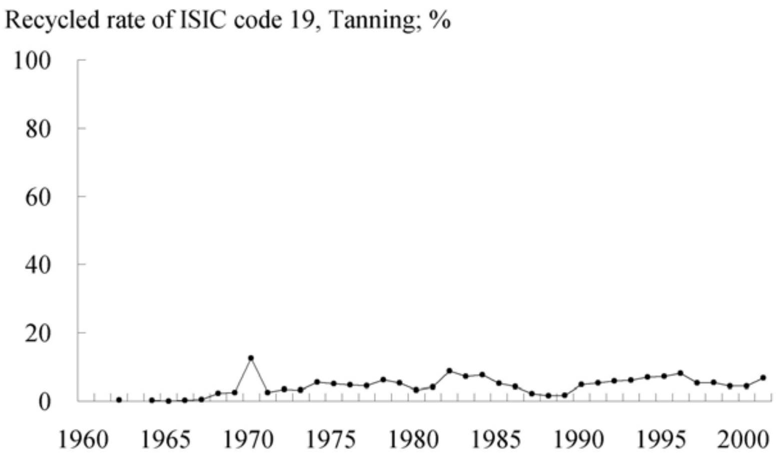


Figure F-7. Recycled water rate in ISIC code 19 of Japan

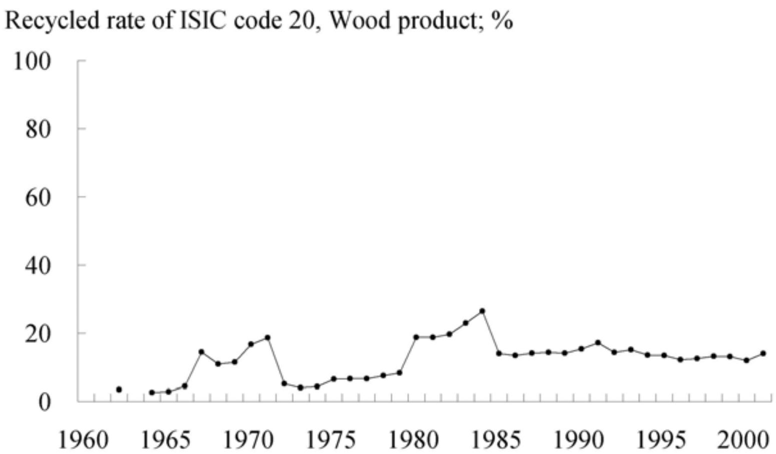


Figure F-8. Recycled water rate in ISIC code 20 of Japan

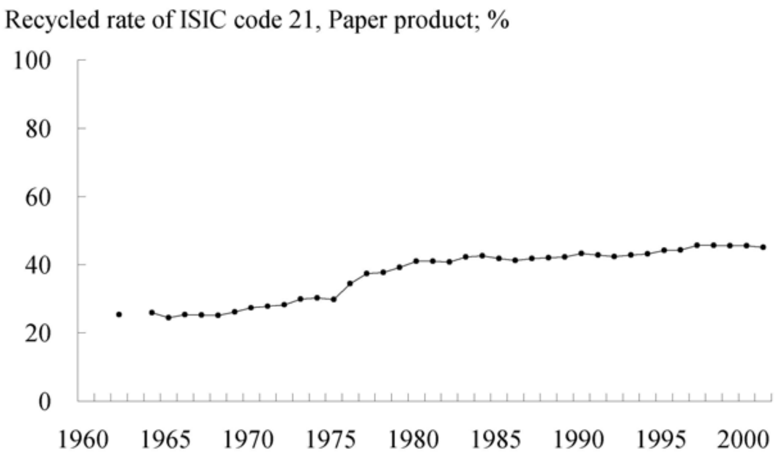


Figure F-9. Recycled water rate in ISIC code 21 of Japan

Figure F-10. Recycled water rate in ISIC code 22 of Japan

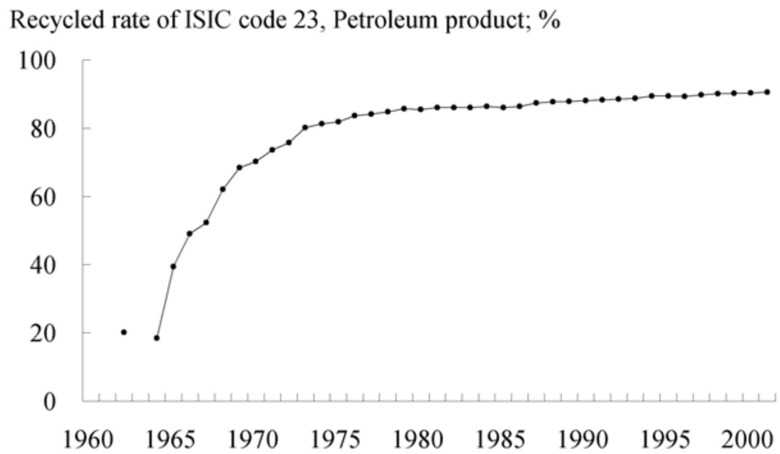


Figure F-11. Recycled water rate in ISIC code 23 of Japan

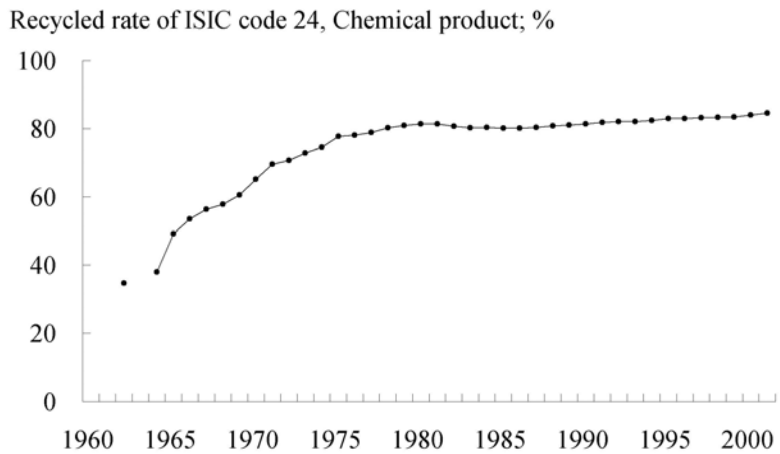


Figure F-12. Recycled water rate in ISIC code 24 of Japan

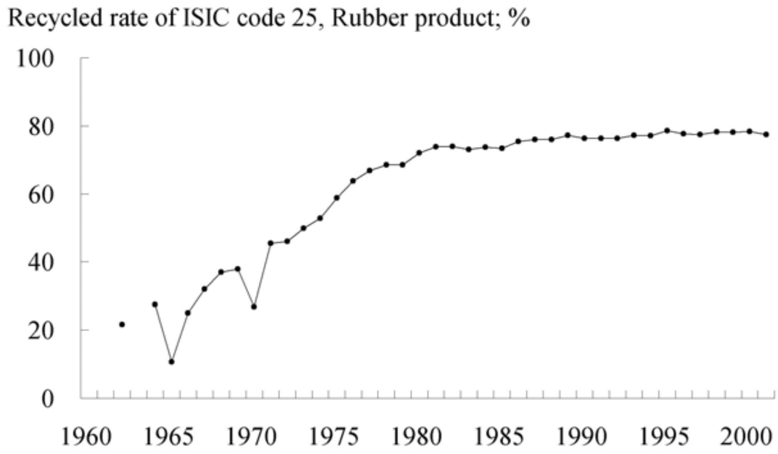


Figure F-13. Recycled water rate in ISIC code 25 of Japan

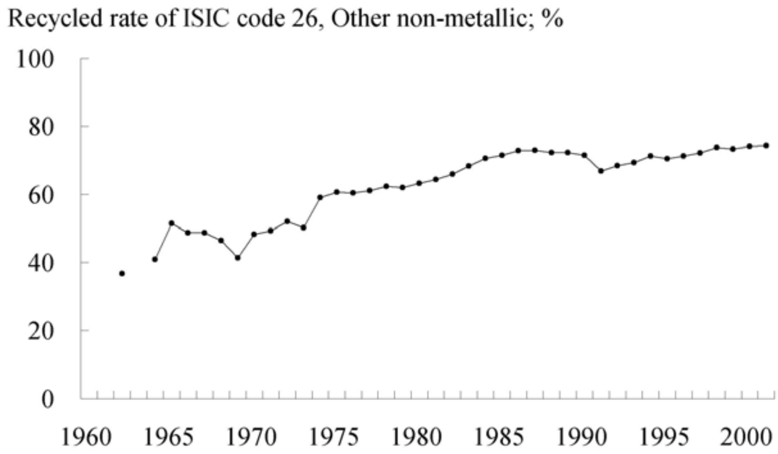


Figure F-14. Recycled water rate in ISIC code 26 of Japan

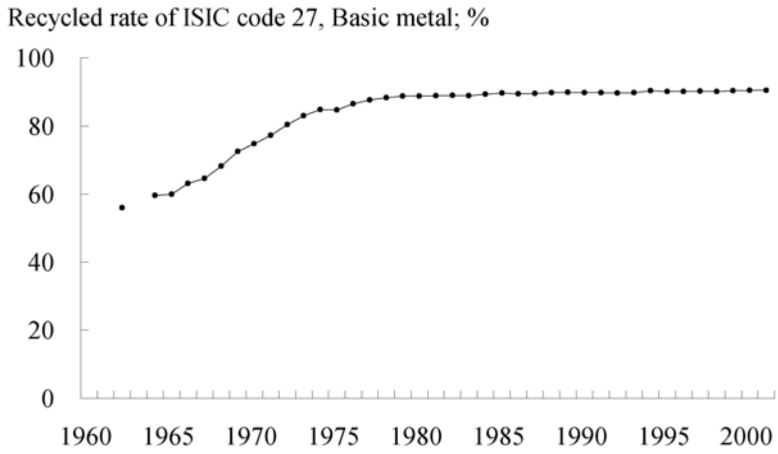


Figure F-15. Recycled water rate in ISIC code 27 of Japan

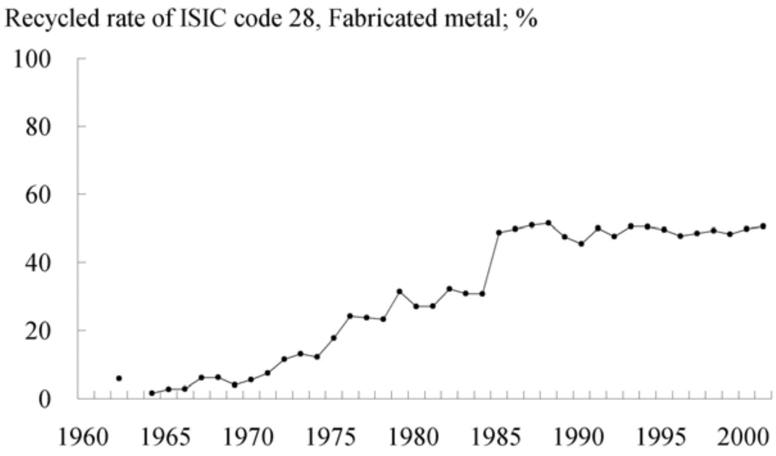


Figure F-16. Recycled water rate in ISIC code 28 of Japan

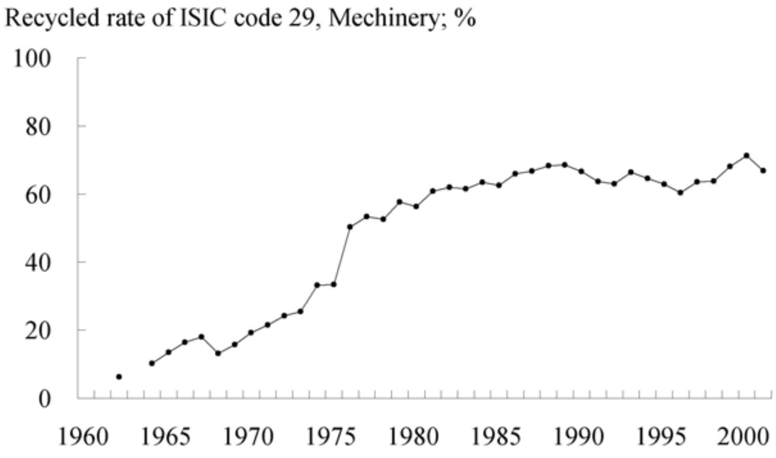


Figure F-17. Recycled water rate in ISIC code 29 of Japan

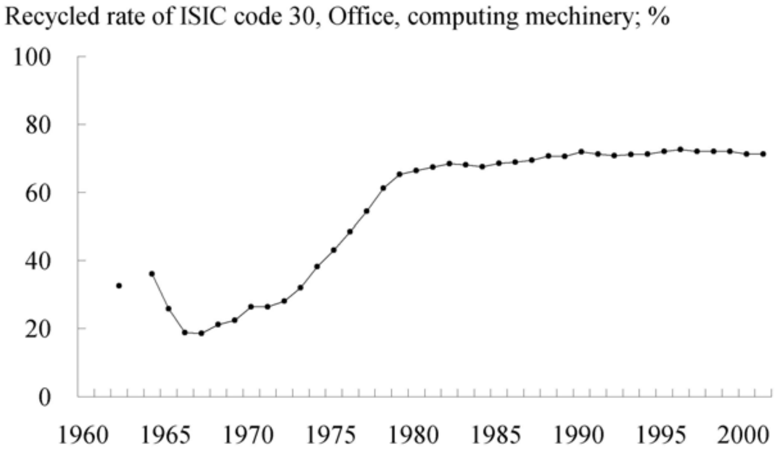


Figure F-18. Recycled water rate in ISIC code 30 of Japan

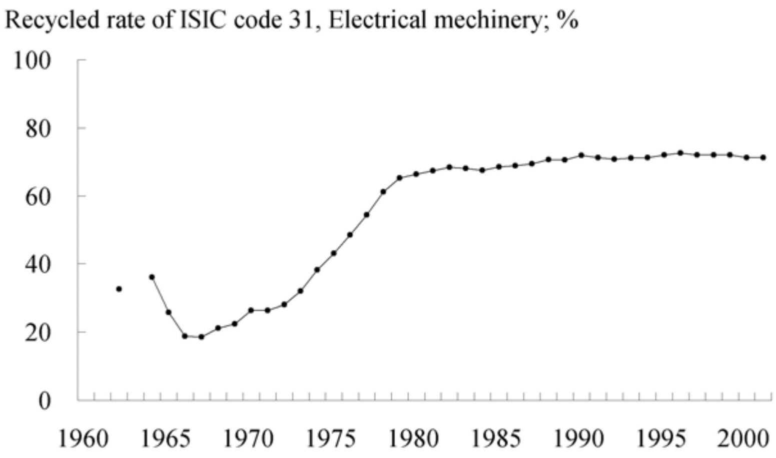


Figure F-19. Recycled water rate in ISIC code 31 of Japan

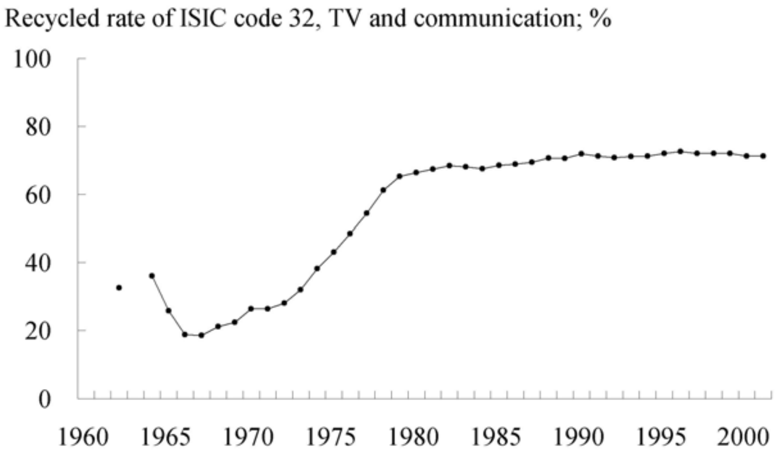


Figure F-20. Recycled water rate in ISIC code 32 of Japan

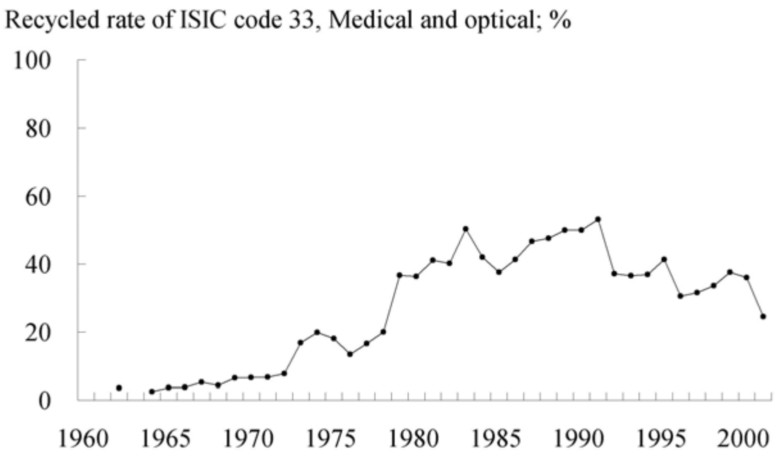


Figure F-21. Recycled water rate in ISIC code 33 of Japan

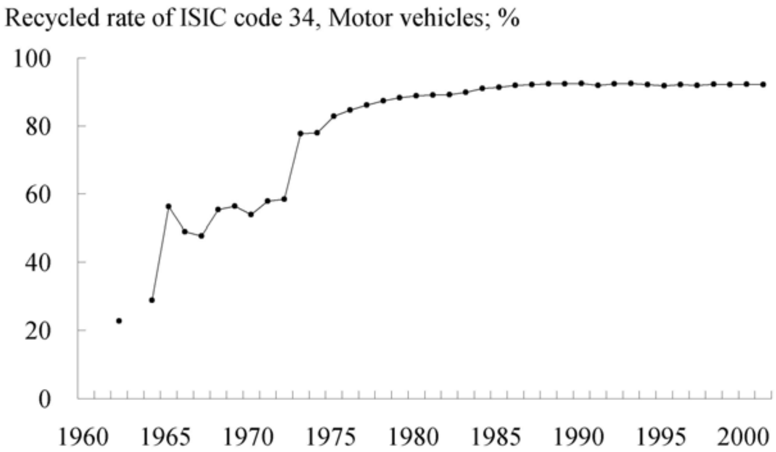


Figure F-22. Recycled water rate in ISIC code 34 of Japan