DISSERTATION

INTEGRATED DECISION-MAKING
FOR URBAN RAW WATER SUPPLY IN DEVELOPING COUNTRIES

Submitted by

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ABSTRACT

INTEGRATED DECISION-MAKING FOR URBAN RAW WATER SUPPLY IN DEVELOPING COUNTRIES

Rapid urbanization and development are causing severe problems of raw water extraction and related environmental and social impacts in developing countries. This study demonstrated that an integrated approach to decision making could help solve these problems. A case study of raw water management in the region of Jabotabek, Indonesia, which is in and around Jakarta, exhibited social and environmental problems including land-subsidence. The integrated approach was applied in a simulated planning process for raw water development, to include consideration of the economic, environmental and social demands, the hydrological system, and the institutional systems that exist in particular areas.

Simulation and optimization techniques (Supply_sim model) were used to determine the planned water allocation for a series of demand clusters for a suite of alternatives and development strategies. A multi-criteria decision analysis (MCDA) based on a decision support system (DSS) was used as an Integrated Decision-Making model to analyze the important and related aspects as one integrated system and to find the best set of decision options.

The overall result of the study showed that the integrated approach could improve the decision process to solve the problem. However, its success ultimately depends on the political will of the government to apply the approach. The government needs to improve coordination among the institutions related to raw water supply development and to carry out a transparent decision-making process. Regulations on land-use planning, groundwater abstraction and water pollution control should be applied strictly and aimed to maintain raw water sources.

The study also showed that a decision process tool such as the DSS within an integrated framework of decision making could help decision makers to reach consensus and gain stakeholder participation, accountability and commitment to the decision being made. In dealing with complex raw water problems in large cities, the study also showed that planning systems could help decision makers to think systematically to improve the decision results.

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CHAPTER 1

INTRODUCTION

1.1. Statement of Problem

Severe problems related to raw water development occur in some developing countries and result in over-drafted aquifers and various environmental and social problems. The countries that suffer the worst problems are often experiencing significant economic growth from industrialization and commercial services that create urbanization and rapid growth of urban and industrial centers in the surrounding large cities. Water demands increase as these centers grow, and the solutions to fulfill the demands are based on the fastest and cheapest approaches, such as groundwater withdrawal. Several large cities in Southeast and East Asia have experienced especially severe problems that include shortage of raw water availability to sustain urban population, industries and economic growth; and environmental and social problems as impacts of economic development. It is apparent that better planning of raw water development will help these countries to grapple with the many development issues they face.

This study focused on the decision-making process of raw water supply development with a case study in Indonesia, where the rapid growth of industrial and urban areas surrounding the city of Jakarta has resulted in severe environmental and social problems such as those described. Rapid growth of urban and industrial water demands could not be fulfilled due to limited local raw water sources and funds to build new regional raw water infrastructure (e.g., reservoirs, conveyance systems for trans-basin water transfer). The easiest solution to sustain the urban population and economic growth is by using deeper groundwater and the government gives permits to some industries and private sector players to exploit deep and semi-deep groundwater aquifers. After several decades, this policy has depleted the aquifers due to excessive groundwater abstraction/withdrawal.

The excessive groundwater abstractions have resulted in drawdown of groundwater tables, seawater intrusion, and severe land subsidence in parts of Jakarta, Tanggerang and Bekasi in Indonesia. Drawdown of groundwater tables has caused the poor urban people who rely on water from their shallow wells to lose access to their water because their wells go dry more often. Sea-water intrusion has made water in their shallow wells turn brackish. These conditions force poor urban people to buy more expensive water for their basic needs. Finally land subsidence is irreversible resulting in a loss of storage capacity in the aquifer for future generations. Obviously, many severe problems are caused by the current raw water policies, and conditions are similar in other Asian countries.

1.2. Research Questions and Hypothesis

From the preceding problem statement, questions that motivate this research are:

- *What are viable solutions to help solve these problems?*
- *Will such solutions really help to solve problems generated by raw water shortage in large cities of developing countries?*

- *How can solutions best be applied, what will the results be, and what are the obstacles?*

Around the world, the solutions needed for such complex problems must come from an integrated approach for the decision-making process of raw water development that takes into account the economic, environmental and social demands, the hydrological system and the institutional system that exists in a particular area. To know whether this integrated approach can help solve raw water shortage problems in the real systems of large cities in developing countries will require analysis based on case studies to help develop the theory. The theory rests on the validity of the integrated approach, and the research questions can be converted to a hypothesis for the study as follow:

- *Can the concept of the integrated approach be applied to help solve the problems generated by raw water shortages in large cities of developing countries?*

This generalized hypothesis will require a valid explanation of what is meant by the integrated approach, which is in all cases a complex concept.

1.3. Research Objectives

The focus of the study is on the decision-making process for raw water supply development in large cities of developing countries with rapid industrialization. The objectives are to apply and establish the concept of the integrated approach to improve decisions resulting from the planning process of raw water development. The specific objectives are:

a. Comprehensively review problems of urban raw water supply in large cities of developing countries that are related to economic development.

b. Develop a framework for an Integrated Decision-Making process and an Institutional Arrangement model to be applied to raw water supply development.

c. Develop a simplified spreadsheet-based decision support system (DSS) model that includes a general multi-criteria decision analysis (MCDA) model and a simulation (Supply_sim) model to analyze important factors of raw water supply development as an integrated system and to help identify the best alternative solution.

d. Apply the model to a case study of raw water supply development of Jabotabek (Jakarta and its surrounding urban centers).

e. Draw important lessons from the case study to test the hypothesis and evaluate the effectiveness of the integrated approach.

1.4. Research Methodology

Several methodologies and tools are used to identify, assess, and evaluate raw water problems and the strategies to solve the problems.

1. Systems thinking and process modeling are used to identify the elements of raw water problems in developing countries and their interrelationships (i.e., the causes and effects of problems).
2. Inventory and classification techniques are used to identify the quantity and quality of available raw water sources, as well as location-based variables relative to water demand and delivery constraints. These techniques are also used to identify agencies or organizations and their roles or responsibilities in raw water development.

3. A simplified system simulation model (Supply_sim) is used to determine the best water supply allocation to each demand cluster, the percentages of supply water per water demand that can be fulfilled, and the best sources of raw water supply. The model helps to simulate and determine the allocation of flows for each cluster based on the purpose of a particular supply alternative. From many raw water sources, the model can provide 100% of the supply needed to meet the demand for some clusters and the other clusters can receive most of the supply needed to meet their demands. Where the entire demand cannot be met, the model can help identify strategies to equitably allocate the shortages to the demand clusters.
4. A general MCDA model (Fontane and Arabi, 2009) is used to analyze the important factors of raw water supply development as an integrated system. The result will be the ranking of best alternative development plans with supporting data.
5. The MCDA tool requires ratings which are the performance of an alternative with respect to the specified criteria. Ideally these ratings are based on measured data or expert judgment. Developing countries often suffer from a lack of data and a lack of experts. Therefore, a logical assessment tool to evaluate the performance of alternatives is presented. Logical assessment is based on propositional logic and can be used to develop inferences about ratings or even criteria to be included in the MCDA.
6. A case study will be used to analyze whether the proposed integrated approach might help solve problems of raw water shortages in Jabotabek.

1.5. Research Benefits

The Integrated approach considers important factors that relate to raw water development, such as the institutional system, hydrological system, and economic, environmental social conditions that exist in individual places. It analyzes all influencing factors of the system as one integrated whole unit and it should produce effective decisions to deal with complex problems of raw water shortage in large cities in developing countries. It is hoped this research will lead to a new and more effective strategy to manage raw water supply development of large cities and prevent problems that may emerge. In addition, the research promotes an appropriate decision-making process that takes into account all important and related aspects of the problem. The developed tools provide a framework and a starting point to help decision-makers better analyze complex problems, hopefully reach a consensus and gain commitment for the decisions being made. The use of simplified models serves to provide tools that work with limited data initially and then serve as a bridge to the use of more complex models when additional data becomes available.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

The literature review begins with water related issues and their impacts on economic development. This discussion is followed with another one about changes in water management practice. Water-related problems exert important influences on economic development and are the reason why this study is needed. These water related impacts on economic development are common experiences in many developing countries, especially those with fast growing industrialization that causes negative social and environmental impacts in those countries.

The topic of change in water management practice is stimulated by the environmental movement and its concern about impacts of natural resource development projects. After the principles of environmental assessment (EA) became laws and regulations, they evolved to include assessment on impacts of development on social issues and on promoting sustainability. From there, a paradigm shift occurred in water management. Now it recognizes the need to integrate all environmental, economic and social issues into an overall management philosophy, process and plan. Water is needed not only to fulfill people's needs but also to meet ecosystem needs as a part of a global life-supporting system. The result of the 1992 UN Earth Summit in Rio de Janeiro paved the way to promote and apply this new water management practice around the world, either through campaigns or policies of global financial institutions. Through the environmental policy, any countries that seek loans from the financial institutions are required to apply the new water management practices.

Topics that are addressed provide a definition of raw water supply systems, an explanation of the integrated approach to raw water development, and a review of current studies about the integrated approach for decision-making.

2.2. Water-related Problems as Impact of Economic Development

In the past two decades, there has been rapid economic growth in developing countries, especially in East and South-East Asia. Industrialization and commercial services became the major driving force of economic development for those countries, but they also create urbanization and the rapid growth of industrial and urban center in surrounding large cities. As the centers grow, water demands increase and deplete local water resources. At the same time, the growth degraded these water resources with their wastes. Some large cities in Southeast and East Asia have experienced severe problems that include shortage of raw water supply and the environmental and social problems as impacts of economic development.

Including water related problems as impacts of economic development are: (i) shortages of water supply for municipal and industrial demands, (ii) environmental impacts (e.g., excessive groundwater abstraction, groundwater and surface water pollution, and watershed deterioration, erosion and sedimentation), (iii) social impacts, and (iv) financial issues. Details of problems and their impacts in developing countries are explained below.

2.2.1. Shortage of raw water supply.

Shortage of water supply generally comes from the rapid increase of total water demand due to the growth of industrial and urban centers in surrounding large cities. To deal with this problem, most developing countries choose the fast and cheap approach by using groundwater abstraction/withdrawal to fulfill water demand. The government gives permits for using groundwater to the industries and urban developers in order to keep the economic growth.

Exploitation of groundwater is simple and inexpensive, and the costs of treatment and distribution are cheaper comparing with those of surface water. Increments of demand can be satisfied with small progressive increases in investment in groundwater exploitation. Meanwhile surface water requires huge capital investments for getting the water (i.e., water rights, reservoir/intake structures) and for the conveyance systems. The tendency in most cases in developing countries is that industrial and urban centers (cities) will continue to use groundwater as the low-cost water supply option for as long as possible, and as long as there is no obvious evidence of a harmful effect (Edworthy, 1993). If the trend continues, groundwater abstraction may become excessive and beyond the availability of the aquifer to support.

2.2.2. Environmental Impact

The environmental impacts associated with water resources are excessive groundwater abstraction, water pollution (groundwater and surface water pollution), and watershed deterioration, erosion and sedimentation.

2.2.2.1. Excessive Groundwater Abstraction

Ground water is used intensively in urban areas for household needs in many developing countries. People who live in small new urban centers in which piped water supply networks have not yet reached their houses usually depend on shallow well groundwater for household needs. Medium and large new urban centers as well as some industries may get water supply from deep/semi-deep groundwater and transfer it through local water supply networks. They try to be self sufficient locally in water supply before they can get more reliable piped water from the water supply company.

Declining ground water tables are the most immediate result of excessive groundwater abstraction. A significant decline/draw-down of groundwater table may result in secondary impacts such as intrusion of salt water in coastal areas and land subsidence. Intrusion of salt-water as well as significant decline/draw-down of the groundwater table causes water inside shallow wells to become saline or dry. Finally, those who get the most negative impact of this problem are the poor urban people, since they can not get water for household needs from their shallow wells.

Saline water in shallow wells has been found in northern and central part of Jakarta, the capital city of Indonesia (DGWRD, 1992). In many other part of Jakarta, shallow wells often become dry especially in the dry season, a condition that never happened in the past decades. An excessive groundwater abstraction for industrial water supply in Guangzhou, China has caused drawdown of groundwater tables more than 60 meters (Chen Mexiong, 1982). Lie Xizeng (1990) and Ji Chuanmao (1982) reported that about 20,000 km2 of areas in China is severely affected with groundwater table drawdown of up to 60 meters. Intrusion of salt water to shallow wells due to drawdown of groundwater table has been reported occurred in Bangkok (Buapeng, 1989) and in Manila (Binnie and Patners, 1986).

Another secondary impact of excessive groundwater abstraction is land subsidence. The deep alluvial aquifers exploited for groundwater supply in many coastal cities commonly contain extensive compressible layers. As groundwater tables decline and their layers drain, subsidence develops to the extent that surface land may fall up to several meters. Continuous land subsidence will be dangerous for the structure of buildings and infrastructure facilities that stand on these layers of soil.

Topographic surveys showed that during the period of 1978-1990 the surface lands in northern part of Jakarta had subsided between 10cm-100cm (DGWRD, 1992). The most recent data (Wiwoho, 2010, no map available) said that additional land-subsidence within 2002-2010 is between 11--116 cm, in which the deepest one is found in northern part of Jakarta, and spread to become less deep to central and southern part of Jakarta. Bangkok suffers serious land subsidence problems by up to 1.0 meter of several hundred square kilometers in the central and eastern part of the city (Edworthy, 1993). Land subsidence in Tianjin reaches 1.5 m within an area of 2,300 km2, while in Shanghai was up to 2.4 meters (Chen Mexiong, 1982).

2.2.2.2. Groundwater Pollution

Excessive groundwater abstraction also generates more spreading of groundwater pollution. When groundwater is pumped up excessively, the suction pressure and/or the empty pores in the ground that previously filled with water will fill water from other parts of the aquifer (including polluted water). If there is pollution in surface/groundwater, this could generate spreading of groundwater pollution.

Groundwater receives pollution mostly from the land surface, whether it comes from human wastes or industrial wastes. Human wastes are the primary contaminant source of groundwater in developing countries, especially in poor urban settlements with inadequate sanitation and waste/garbage disposal. The second major contaminant source is industrial liquid wastes. Economic development based on industrialization generates urbanization, and this causes more human and industrial wastes. Severe contamination of highly valuable groundwater resources has been found in the vicinity of Shanghai by arsenic from industry (Hu Xiushu, 1985). Tian and Wang (1985) reported that industrial wastewater causes serious chemical contamination of groundwater in the Beijing area.

Other sources of groundwater contamination may also come from salt-water intrusion and polluted rivers that run through groundwater recharge areas. Both kinds of contamination are stimulated by intense or excessive abstraction of groundwater either in coastal areas or in groundwater recharge areas. Saline water in shallow wells has been found over large areas of Jakarta, Indonesia, due to salt-water intrusion. In the coastal area of North Jakarta, the saline water is more intense and it occurs all the time in shallow wells. Meanwhile shallow well water in Center Jakarta is less saline compared with that in the coastal area, and it happens primarily in the dry season (DGWRD, 1992).

2.2.2.3. Surface Water Pollution

In the poor dense-urban settlement, people often dispose their domestic fluid waste into drainage canals, creeks or rivers as this traditionally happens in the villages in rural areas. For taking a bath and so forth, they use a public bathroom or the river. In the more developed urban centers, they dispose their domestic fluid waste into cesspool pits or septic tanks, but these sometimes overflows due to low permeability of the shallow layers (clay), and the overflows go directly to the drainage system.

Industrial waste is the second great contributor to surface water quality pollution if a proper disposal procedure is not implemented. Law enforcement of regulation related to pollution control in developing countries is generally much weaker compared to industrialized countries. Storm run-off is the third contributor of surface water pollution as rainfall flushes out contaminants and wastes from urban areas. Traffic emissions, construction residue, uncollected garbage, spills of industrial products and wastes (i.e., solvents, lubricating oils and fuels) from local services (e.g., garages, fuel station) are washed off by runoff from urban areas to water bodies or rivers. This kind of urban run-off has contributed to the decline of water quality in almost all of the rivers that flow through the cities.

2.2.2.4. Watershed Deterioration, Erosion and Sedimentation

Economic development creates not only new industrial and urban centers, but also land use changes. In areas surrounding Jakarta, Indonesia, large irrigation areas have been converted into several industrial and urban centers. The same condition has also happened in other large cities. The land-use changes increase the storm runoff, and it reduces the soil infiltration. When there is a little heavy rainfall, this condition will generate flooding in the surrounding areas, which did not happen in previous years.

Expansion of agriculture land in order to boost economic growth also causes land-use changes. In order to make agricultural products for export and domestic purposes, private companies convert large areas of rural land and/or rain forest to become agricultural areas. Even farmers in the rural villages expand their agricultural land up into the adjacent hills.

All the land-use changes mentioned above will cause negative impacts. In rural, remote and hilly slope areas, the land-use change generates more erosion and sedimentation in the rivers. Erosion of topsoil will reduce soil fertility for plants and bushes to grow. Without plants and bushes covering the land, this reduces ground infiltration and recharge flows, so that less headwater flows and groundwater flows will be available. The land-use changes in the upstream river cause high fluctuation of river flows, and generates higher floods that never happened in previous decades during the rainy season. In urban areas, more frequent floods happen in the wet season, while water in the stream dwindles during the dry season. Also, the shallow wells which poor urban people depend on for household water will be more often dried in the dry season due to smaller recharge flow.

Sedimentation in river streams reduces the hydraulic capacity of the stream and it may cause more flooding to happen. Sedimentation in the dams reduces the life term of the dams. Without proper management, economic development that generates land-use change mentioned above will cause negative impacts to the water resources.

2.2.3. Social Impact

Economic growth in developing countries is indicated by the growth of industrial and urban centers surrounding big cities. The centers stimulate and support economic output, income, investment, and provide a wide range of employment opportunities to a growing workforce. As the centers grow, however, the social impacts may become significant and obvious. The social impacts can be both direct and indirect impacts.

The most significant direct impact of the growth of industrial and urban centers is urbanization, either through settlement of people with skills to work in industrial/urban center or people who work in *"informal"* sectors in the centers (e.g., vendors who provide cheap food for low-rank workers, etc.). The indirect impacts are all impacts caused by both environmental impacts and short of water supply. Decline of groundwater tables due to excessive groundwater abstraction makes the shallow wells go dry. Poor urban people have to buy expensive water from vendors for drinking and cooking, and use polluted river water for other household needs. The victims who get the most negative impact are usually the poor urban people living in the large cities.

As impacts of economic development and urbanization, pollution in river water may have reached a dangerous level for the environment. The pollutants may come from human wastes, industrial effluent discharges and storm runoff that washes out the pollution (e.g., open garbage collection next to traditional market, etc.). All pollutants that may contain waterborne disease (i.e., from human wastes) or heavy metals (i.e., from industrial wastes site) will contaminate both surface and groundwater. Since the urban poor people use untreated water from either shallow wells or rivers, they are vulnerable to diseases caused by the contaminants.

2.2.4. Financial Issue

Economic development in many developing countries has resulted in rapid increase of water demand beyond the capacities of infrastructures in the region to cope with. The municipal and industrial water demands have increased very fast, while agricultural water demand may not decrease. Although these countries have developed their water resources and water supply infrastructure, the growth is slower than that of water demand, because of lack of funding.

In regions of growing large cities, total water demand often exceeds the availability of both surface and ground water resources. As the region grows the water demand increases, so a trans-basin water supply needs to be built to solve water supply shortages in the region. This means that more funds are needed to build conveyances such as canals/pipes, pumping stations, and reservoirs to supply water for the region. This occurs in growing large cities such as Jakarta, Indonesia.

Since building infrastructure for water supply requires a huge capital cost for investment, the funding sector becomes a major constraint in many developing countries. Funds are needed for getting raw water (that may include built reservoir and conveyance systems), water treatment plants and pipe networks. The government alone cannot bear the burden for financing this sector. Therefore, the government should move towards sharing of costs and bringing in institutional finance to share the burden.

2.3. Changing Water Management Practice

In the past view decades; there has been a change in water management practice. The change was initiated by the environmental movement due to negative impacts on the environment and society. These negative impacts are results of improper management and short view thinking in planning and development of water related projects. The previous management practice did not require systematic, interdisciplinary and integrated approaches of natural and social sciences in the planning and decision making of development projects that may have heavy impacts.

The environmental movement also generated a shift of paradigms of water resources management. A concept of "integrated water resources management" (IWRM), "total water management" and "sustainability" have emerged in the policy of water management. A big shift in the practice of water management happened after the 1992 UN Earth Summit in Rio de Janeiro, which aimed to achieve global sustainable development. Then, the World Bank adopted the agreements of the 1992 Rio Earth Summit into its Water Resource Management Policy. As the world financial institution with power through policies and requirements that come with loans, the World Bank encourages developing country's governments to apply the new principles of water management practice as it set in the 1992 Rio Earth Summit. Details of the change are explained in the next two sub-sections.

2.3.1. The Shift of Paradigms in Water Resources Management

In order to cope with problems of negative impacts in water resources development, there has been a consensus of broadening perspective of water and its roles and impacts in economics, society and ecology. Water is needed not only to fulfill people's needs, but also to meet the ecosystems needs as a part of global life-supporting system.

One of the definitions of IWRM is "a process that promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (TAC-GWP, 2000). Since there is no real consensus definition about IWRM, Grigg (2008) proposed a definition of IWRM as "a framework for planning, organizing, and operating water systems to unify and balance the relevant views and goals of stakeholders."

As a matter of fact, IWRM is not a new idea. It emerged in the 1980s as a response to sectoral approaches to water management, and it evolved until it reached its current shape. IWRM derives from new approaches to resource management and planning, which seeks collaboration and consensus building and using a systems approach to resource management. The basic idea is cross-sectoral, participatory-driven, coordinated approaches to land and water management on a watershed/river basin basis.

As follow up of the Rio Declaration, Agenda 21 identifies three sustainability principles for water resources management. They are (1) the ecological principle that requiring integrated management in the river basin with focus on land, water, and environmental needs; (2) institution principle; and (3) economic principle.

In the effort to make progress in implementation of IWRM, the UN encouraged the World Finance Institutions and International Organizations to adopt the Rio Declaration in their policies and decision-makings. This action has caused developing countries that seek help from the World Finance Institutions to implement the Rio Declaration.

Other concepts of water management are TWM (total water management) sponsored by AwwaRF (American water work association Research Foundation) and WFD (water framework directive) from the European Union. Based on the definition by AwwaRF, TWM is the exercise of stewardship of water resources for the greatest good of society and the environment and its basic principle is that water supply should be managed in sustainable basis. TWM encourage planning and management on a natural water systems basis through a dynamic process that adapt changing condition, balances competing uses of water, participation of all units' government and stakeholders, promotes water conservation, and fosters public health and community goodwill (Grigg, 2008).

The Water Framework Directive is a European Community framework for water protection and management, which provides identification of water issues on the basis of river basin districts and adopts management plans and programs that are appropriate for each river basin. The goal is to provide management of inland surface water and groundwater, estuaries, coastal water in order to reduce pollution, promote sustainable water use, protect aquatic environment and ecosystem, and mitigate the effect of floods and droughts.

2.3.2. The Role of International Financial Institutions

As the world financial institution, the World Bank has played a big role in water resources development in many developing countries. The role and power were gained through policies and requirements that come with the loans. Through its programs with the objective of reducing poverty, the World Bank encourages developing country's governments to lower their role in public services and directing it to private sectors. The World Bank policy on water resources sector is known as the Water Resource Management Policy that was issued in 1993. According to the World Bank (the World Bank, 2003), its Water Resource Management Policy reflects agreements in the 1992 Rio Earth Summit and the 1992 Dublin Principles. The purpose of the policy is: (1) to encourage reform in policies, planning, and management of water resources institutions of borrowing countries; (2) to serve as a guideline for the World Bank itself to help borrowing countries in their reformation efforts and means for implementing it.

With its power through requirements that come with the loans, the World Bank wants the developing country's governments to reform their water policies to follow the Bank's policy to support sustainable growth and poverty reduction by being active, mobilizing public and private financing, and meeting environmental and social standards.

The Asian Development Bank (ADB) outlined its vision for water management in the region in its "Water for All" policy. It recognizes that as a resource, water must be managed to meet needs without causing conflict, or stressing natural resources. As a service, people must have access to safe and reliable supplies. ADB recognizes that sustainability of the resource is a key, and that this can best be met by the active involvement of people at all levels (i.e., national and local government, civil society groups, and communities. ADB also noted that managing water resource require a strong political will.

2.4. Raw Water Supply Systems

Raw water for urban water supply is water that being provided for water supply before it goes to the water treatment plant. The source of raw water is from surface water and groundwater, in which surface water generally goes to water treatment plants before it is sent to water supply network. In developing countries, surface raw water supply for both urban and irrigation demands is generally stored in the same reservoir. The quality of raw water entering the treatment plant will influence how far water treatment is needed, and how much the cost is. The worse the water quality entering the treatment plant, the more advanced treatment is needed and the more expensive the cost will be.

The raw water system is a system that covers raw water from its sources (surface water and groundwater), storage water in reservoir or aquifer, and sends water to demand clusters/users through a conveyance system. The water obtained from rivers, reservoir or groundwater wells are based on water rights, permits, leases or transfers. The conveyance system includes canals, pipes, pumps and hydraulic structures to carry water from the sources to the demand cluster/user.

Raw water system is part of urban water supply system that directly links to natural resources (i.e., water). Meanwhile urban water supply system covers a wider area including raw water system or water acquisition, treatment and delivery of treated water. As a part of an urban water supply system, the raw water supply system plays an important role on the availability and quality of the urban water supply. It determines the levels of industrial productivity, human activity, quality of life, and public health.

2.5. The Need for Integrated Approach on Raw Water Development

The most important goals for raw water supply development are to fulfill the water demands that support human activities (i.e., including domestic/household, economic, and industry/commercial), support sustainability of supply (quantity and quality), and take into account environmental and social demands. Since raw water supply development for a growing large city becomes more complex due to some factors such as limited local water resources, the need to keep economic growth, fast growth of water demand, limited fund, and a lot of people (with different interest) impacted by the development, so the most important goals may be forgotten because of conflict of interest among the DMs/stakeholders. This situation will result in problems especially environmental and social.

An integrated approach to raw water development is needed to prevent the negative impacts or problems to the environment and society. The approach should consider and analyze all important aspects are impacted by the development, including the hydrological system, the economic, social and environmental aspects, and the institutional system that exists in the area. If the solution can not satisfy all the goals being set, a trade-off by giving relative importance factors/preferences among the goals should be considered to find the best solution.

2.6. Current Study on Integrated approach for Decision Process

2.6.1. Multi Criteria Decision Analysis

Multi criteria decision analysis (MCDA) is a systematic process to analyze discrete decisions based on concept of an overall score for an alternative. It uses an interactive procedure that can easily be adapted to new information and provides a way to document and audit decisions. MCDA provides a rank ordering of alternatives that help the decision-maker (DM) to choose the best option to achieve their goals. The purpose of using MCDA is to help the DM thinks systematically about complex decision problems and to improve the quality of the resulting decisions.

Most decision situations include the following elements: (1) goals or objectives to be achieved, (2) criteria, constraints or requirements to achieve the goal, (3) decision options or alternatives, (4) the experience and background of the DM(s). There are also a number of players involved in decision situations. The DM is an individual or group that has the authority to make the decision or approve the design. The stakeholders in a decision process are the individuals or groups that can influence the decision and/or are affected by it. Both the decision makers and stakeholders can be thought of as 'decision influence groups." The MCDA is often conducted by a group or individual that synthesizes the subjective and objective inputs of the DM(s) and stakeholders into meaningful inputs for the MCDA software and then organizes outputs into formats that will support the decision analysis process.

Application of MCDA to various aspects of management has been in a number of studies. Duckstein et al (1994) used MCDA on ranking groundwater management alternative, and Tkach and Simonovic (1997) used MCDA to evaluate water resources development options. Hyde et al (2004) proposed to use a stochastic approach within their MCDA to examine the alternative chosen so that the decision maker more confident with his decision is the best. Traore and Fontane (2007) applied MCDA to managing drought impacts. There have been numerous other examples of MCDA applications in the literature including flood plain management and reservoir operations. The many applications of MCDA indicate that MCDA is well suited to water resources planning and can provide a useful tool for the decision making process.

There are several methods or techniques used in MCDA. They are based on different theoretical foundations such as value-based scoring, goal aspiration, outranking, or a combination of these.

1. **Value-based Scoring.** The technique applies numerical scores or ratings to communicate the merit of one option in comparison to others on a single scale. If there are several different scales, all scales are converted into a common numerical scale. Scores are developed from the performance of alternatives with respect to an individual criterion and then aggregated into an overall score. Individual scores may be simply added or averaged, and a weighting mechanism can be used to favor some criteria more heavily than others do. A simple, robust and popular method included in this study is the Weighted Average method.
2. **Goal Aspiration.** The technique relies on establishing desirable or satisfactory levels of achievement for each criterion. These processes seek to discover options that are closest to achieving, but not always surpassing, these goals. Goal models are most useful when all the relevant goals of a project cannot be met at once. Included in the Goal Aspiration techniques is the Compromise Programming method.
3. **Outranking.** The technique compares the performance of two (or more) alternatives at a time, initially in terms of each criterion, to identify the extent to which a preference for one over the other can be asserted. The model seeks to

establish the strength of evidence favoring selection of one alternative over another. Outranking models are appropriate when criteria metrics are not easily added up or combined, measurement scales vary over wide ranges, and units are incomparable. Included in the Outranking technique are Promethee and Electre methods.

4. **Analytic Hierarchy Process (AHP).** The optimal alternative is selected by comparing project alternatives based on their relative performance on the criteria of interest. AHP is a value-based scoring approach; however, AHP uses a quantitative comparison method that is based on pair-wise comparisons of decision criteria, to determine the criteria weighting values. Decision-makers express the intensity of a preference for one alternative over another with respect to an individual criterion using a nine-point scale:

   1 : if the two elements are equally important
   3 : if one element is weakly more important than the other element
   5 : if one element is strongly more important than the other element
   7 : if one element is very strongly more important than the other element
   9 : if one element is extremely more important than the other element

   All individual criteria must be paired against all others and the results compiled in matrix form. For each comparative score provided, the reciprocal score is awarded to the opposite relationship. The normalized weight is calculated for each criterion using the geometric mean of each row in the matrix divided by the sum of the geometric means of all the criteria.

In this study, only the popular and simple method that also easy to be applied in spreadsheet will be used here. They are the Weighted Average, Compromise Programming, and Promethee_WAM methods. More detailed analysis of the theoretical foundations of MCDA methods can be found in Appendix E3, Mollaghasemi and Pet-

Edwards (1997), Belton and Stewart (2002), Saaty and Vargas (2001), and other references.

2.6.2. MUA and Decision-making Process

MUA (Multi-attribute Utility Analysis) is a tool for evaluating several attributes (e.g., quantitative or/and qualitative attributes) on the same basis. The concept of MUA is almost the same as the MCDA Weighted Average method. MUA has been applied to perform trade-off analysis in order to help the decision processes in Tampa Bay Water, the largest wholesale water supplier in Florida, (Tampa Bay Water, 2006). A DSS model called SMARTT was developed for Tampa bay water by applying MUA in the spreadsheet to find a balance among a number of conflicting attributes (or objectives) and to find "the best" solution. The objective of SMARTT model is to determine the best mix of supply source of water which meets the agency's policy objectives: (i) to minimize operating cost, (ii) to improve environmental stewardship, (iii) to ensure source reliability, and (iv) maximizing water quality. Water quality is part of the contractual agreement with water user, so it has minimum level of quality, meanwhile operating cost, environmental stewardship, source reliability can be traded-off among each other to find the best mix of supply source of water.

Under the "Consolidated water use permit", Tampa Bay Water has to reduce its groundwater extraction from 192 mg/d in 1998 to 90 mg/d by December 2007. The agency has to develop alternative new sources of water supply including surface water and desalinated water. Decreasing downstream river flows due to surface water acquisition will increase salinity level and have impacts on the ecology/environment in the river's estuary in Tampa bay. To limit this impact caused by surface water acquisition, desalinated water is considered as one option among other options of source water.

Four measures were selected for the "Improve environmental stewardship" objective. Three of them are monitoring of salinity change in stream flows at downstream of diversion locations; the Alafia river, the Tampa bypass canal, and the Hillsborough river. The other measure is predicted groundwater level changes at specific control points in the aquifer systems that are related to volume of groundwater abstraction. Measures for the "Ensure source reliability" objectives are reserve capacity in reservoirs, groundwater permit limit, and groundwater abstraction in the current month. The groundwater permit limit serves as the threshold which constraints the model in terms of allowable groundwater pumping each year.

The measure for the "Minimize operating cost" objective is the operating cost per 1000 gallons of water, mixed from any of four alternatives of water sources. These sources are groundwater, treated surface water (with the reservoir), water purchased from the city of Tampa, and desalinated water. Operating cost was estimated for each of supply source, based on the expected cost of chemicals and electricity required to treat and deliver water from each source and the amount of water selected.

The SMARTT model is used to determine trade-off among three objectives (i.e., minimizing operating cost, improving environmental stewardship, and ensuring source reliability) from using four source of water supply and to use water quality as constraint. Calculations from 5 supply scenarios (or alternatives) of mixed water from supply sources are evaluated versus measures of the three objectives above. The objectives and measures perform as criteria and sub-criteria that should be achieved, and each of them has importance/weight factors that were determined by the decision-makers (i.e., the Board of Directors). Data for the model includes (i) projected water demand, (ii) forward-looking seasonality (i.e., wet or dry season), (iii) reservoir elevation, (iv) groundwater withdrawal, (v) groundwater permit limit, (vi) target level of water quality parameter, (vii) supply source constraint, and (viii) estimated operating cost, for each of supply source. The model is used to find the best mix of supply source of water based on trade-offs among three objectives mentioned above. The result will be used as optimized regional operating plan (OROP).

MUA (Multi-attribute Utility Analysis) in the SMARTT model helps the decision-making process and integrates: (i) decision-makers' policy objectives, (ii) possible/ alternative solutions of problem (e.g., mix of supply sources), (iii) available information from different viewpoints (e.g., cost, environment, etc.), and (iv) an understanding of trade-offs.

CHAPTER 3

INTEGRATED DECISION-MAKING

FOR URBAN RAW WATER SUPPLY IN DEVELOPING COUNTRIES

3.1. Introduction

A cause-effect model based on system thinking approach and process modeling is introduced in this chapter to explain the complex and interacting problems discussed earlier. As shown on Figure 3.1, a holistic view of how the raw water problems developed can be gleaned from the model to explain and identify the elements that caused the problems, their interrelationships, and the actions needed to deal with the problems.

The model is similar to others that seek to demonstrate chains of effects that begin with "driving forces" that lead to a "present condition," which causes "pressure" and then "impacts". Action is needed to influence the "driving forces", "present condition" and "pressure" to prevent or reduce the negative "impacts". An example of a framework like this is the DPSIR causal effect model, which stands for "Driving Forces-Pressures-State-Impacts-Responses" and is used widely around the world.

Figure 3-1 includes several items of relevant information to explain the causes and effects. Most of these have been introduced earlier and will be discussed in more detail later.

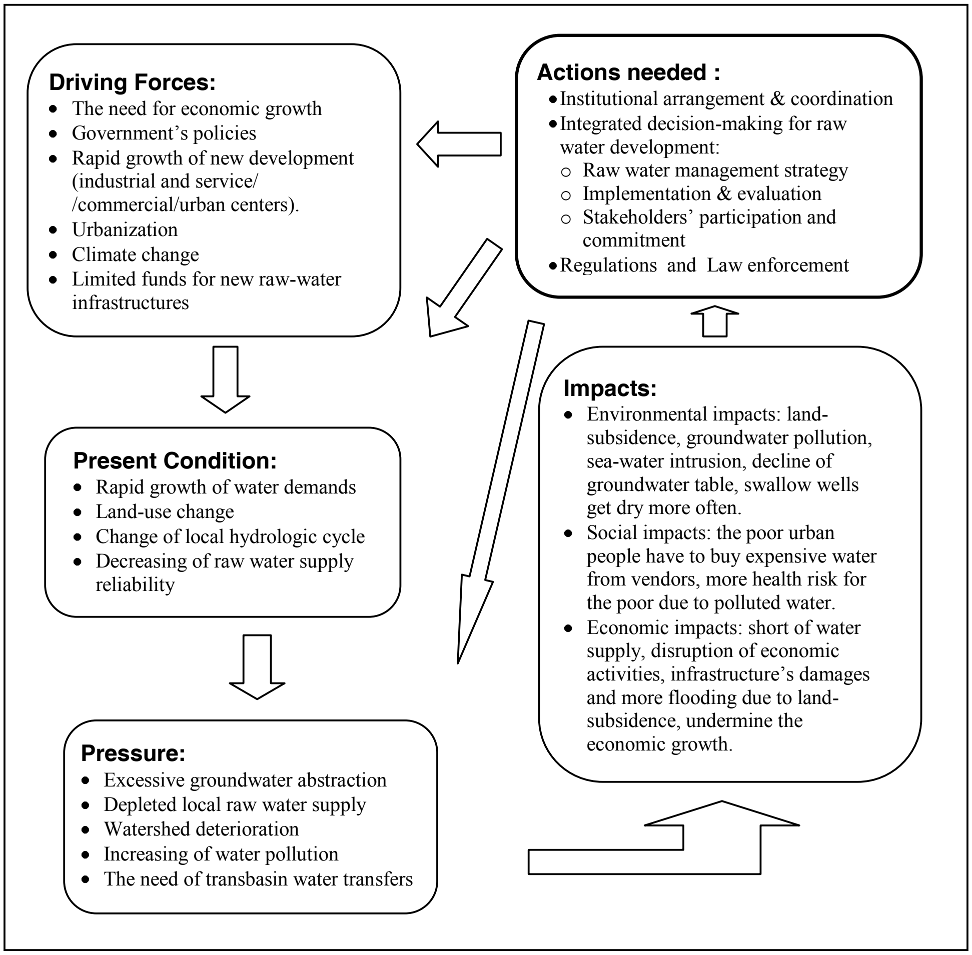

Figure 3.1. The Cause-Effect model for raw water problem in developing countries

3.2. Integrated Decision-Making for Raw Water Development

After the causes and effects of the problem have been mapped, Integrated Decision-Making (IDM) is needed as a framework for the decision-making process to analyze all important aspects of the system as an integrated whole system. The purpose of the IDM is to improve the quality of the decisions and to prevent negative impacts caused by them. The best decision that solves the problem is sought and based on a thorough understanding of the problem and careful analysis of all of its important aspects.

The important aspects of IDM are addressed in a framework model, which addresses hydrologic, institutional, technical, economic, environmental and social aspects (Figure 3-2). The analysis and decision-making processes of the IDM are carried out through a Decision Support System (DSS).

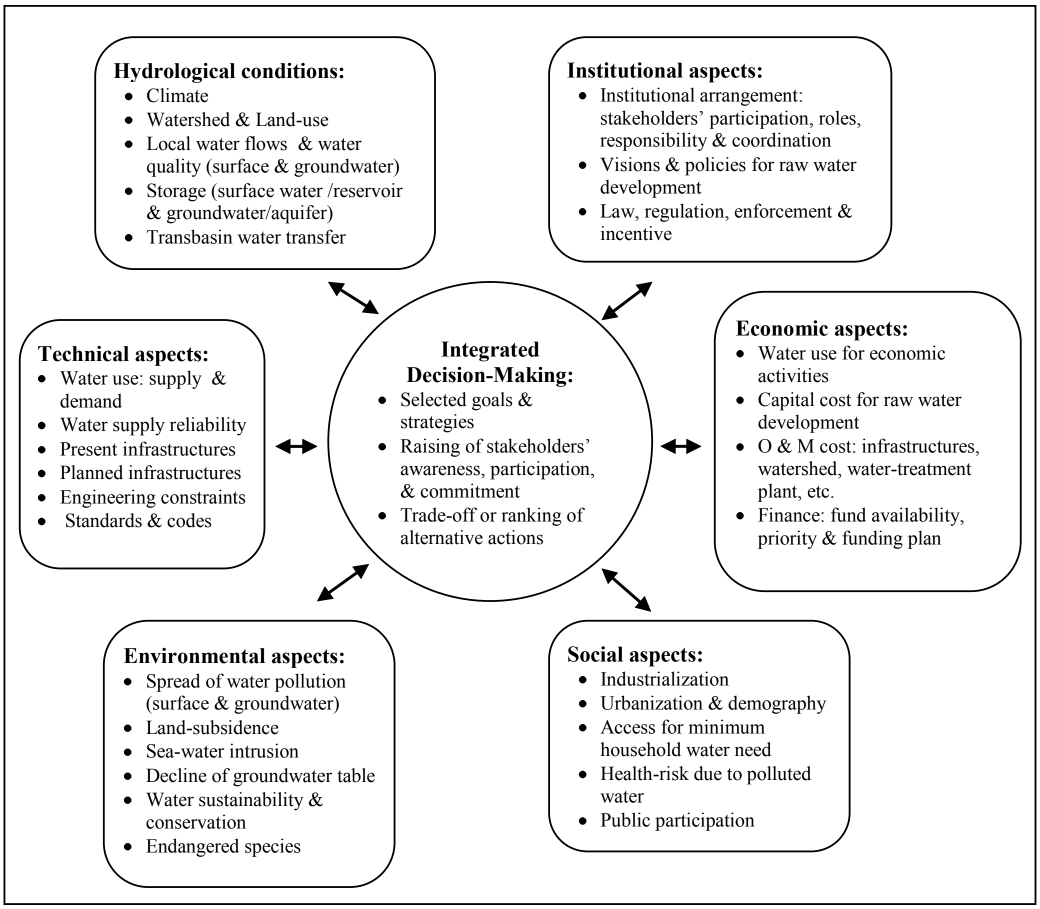

Figure 3.2. Important Aspects of IDM for Urban Raw Water Development

The DSS part of the IDM model applies MCDA using a spreadsheet to analyze the important aspects as one integrated system and to find the best decision options. The main elements of the DSS model are alternative actions/programs, criteria/sub-criteria, matrix evaluation, decision-making process, and decision results. The criteria/sub-criteria that represents the objectives and the strategies for raw water development are used to evaluate all possible alternatives for the development.

The DSS for IDM is used to help the decision makers (DMs) think systematically when dealing with complex problems and to find the best decision options that might be used to solve the problem. The DSS is also used to help to reach consensus among the DMs and stakeholders, and to gain stakeholder participation, support and commitment to the decision being made.

3.3. Framework Model of Integrated Decision-Making

A framework model of Integrated Decision-Making for urban raw water supply development is presented in Figure 3.3, which explains the stages of Integrated Decision-Making for urban raw water supply development to reduce the negative impacts of the raw water problem. A detailed explanation of the framework model is presented in Table 3.1., which includes the components and the expected results of every stage. The details are important and embody the best principles of integrated water resources management based on international practice.

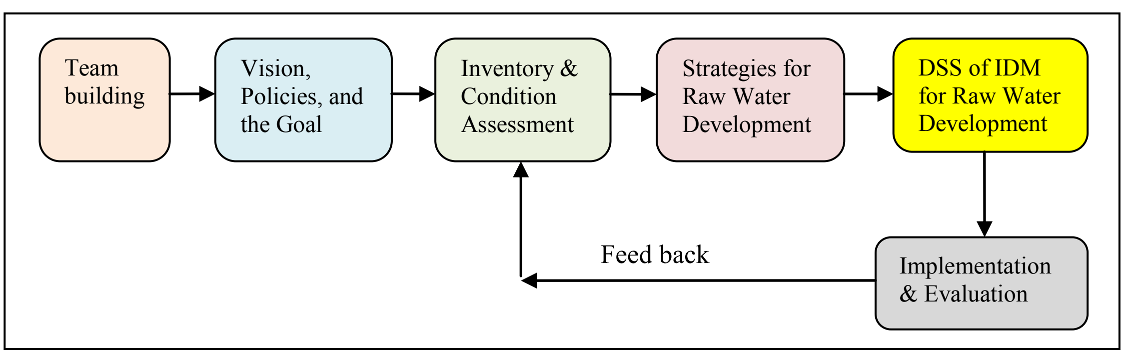

Figure 3.3. Framework model of Integrated Decision-Making

Table 3.1. Details of Framework Model of Integrated Decision-Making for Raw Water Supply Development

Overall Goal	To fulfill urban raw water demands that support economic growth and to reduce its negative impacts on society and the environment.	
Stage:	Components:	Expected Results:
Team building	• Problem identification and/or "what needs to be done". • Stakeholder identification. • Enhance stakeholder's participation through workshop, consultation, survey, and representation in the planning management structure. • Institutional Arrangement, including its management structure for coordination and control.	• Raising awareness among stakeholders about problem happening, what needs to be done, and the need of collaboration. • A framework for broad stakeholder participation. • A team for the planning program with its management structure. • Political will and support for the planning process.
Vision & Policies	• IWRM, Total Water Management, Water sustainability. • Linking long-term vision to medium/short-term targets. • Horizontal linkages across sectors, so that there is a coordinated approach to development. • Vertical spatial linkages, so that local, national and global policy, development efforts and governance are all mutually supportive. • Raw water development that support national economic growth. • Prevent or reduce its negative impacts on society and the environment.	• Definite raw water management and development policies.
Inventory & Condition assessment	• Supply & demand of raw water • Raw water sources (local & regional) • Existing infrastructures • Economic growth & development • Impacts of regional development • Previous planning • Possibilities of infrastructures upgrades or having to build additional infrastructure. • Watershed of the water source • Transbasin water transfer • Fund availability and its sources	• General plan of all possible raw water supply development options. • Priority of development of projects based on their urgency. • Fund availability and its sources.

	• Existing laws & regulation	
Strategies for Raw Water Development	Alternatives raw water management and development strategies, including: • Maximize use of existing infrastructures. • Apply zoning for ground water abstraction to reduce further environmental damage. • Provide enough surface raw water supply to reduce groundwater. • Apply mixed raw water supply from surface water, groundwater and desalinated water for certain designated area/zone. • Apply high tax on groundwater abstraction. • Increase water fee (tariff) and apply cross-subsidy to help the poor urban people. • Minimize cost for building new infrastructures.	• Definite raw water management and development strategies.
DSS for IDM on Raw Water Development	• Hydrological system analysis • Technical/engineering analysis • Economic analysis • Social & environmental impact assessments • Decision Analysis through MCDA • Trade-off or ranking of alternative's actions • Detail of planned actions	• Detail of approved planned actions and their time schedule. • Fund for the development project, its sources and budget schedule. • Transparent decision making process • Stakeholders' understanding & involvement in decision making process. • Support and commitment for the implementation of decision.
Implementation & evaluation	• Monitoring of implementation-progress and its impacts. • Evaluation. • Change or modification of planned actions as needed.	• Result of implementation in every stage should be within the range of target of short/medium/long-term goals.

3.4. Institutional Arrangements

The framework model must include institutional arrangements that start with stakeholder identification to identify the lead, core and influencing-stakeholders, the support agencies, raw water users, and participant and advisory groups. In developing countries effective institutional arrangements are difficult to arrange because governance systems may not be effective and there may not be systems of shared values among diverse populations, a problem that is often exacerbated by lack of meaningful public participation.

Since raw water supply sources are in the public domain, the lead and core decision makers or stakeholders are usually government agencies which represent the government and public interest. The government agency that is responsible for raw water supply development becomes the-lead DM/stakeholder. The national board of planning that is responsible for medium and long-term development should be the influencing stakeholder in many developing countries.

Figure 3.4. shows a general model for institutional arrangements for raw water supply development. Notice on the model four main groups that are engaged in raw water decisions. These are core DMs, which comprise the water management authorities. The supporting government agencies undertake roles of either direct support or regulatory control. The raw water users are at the level of local governments and utilities, and they include the private industries and companies who may carry out about the same functions as utilities. One group of stakeholders is shown at the level of the agencies, that is, the participant and advisory group. The other is labeled "influencing stakeholders" because its members have great influence but are not directly involved in water management. The lead DM is shown at the top to provide overall control and coordination.

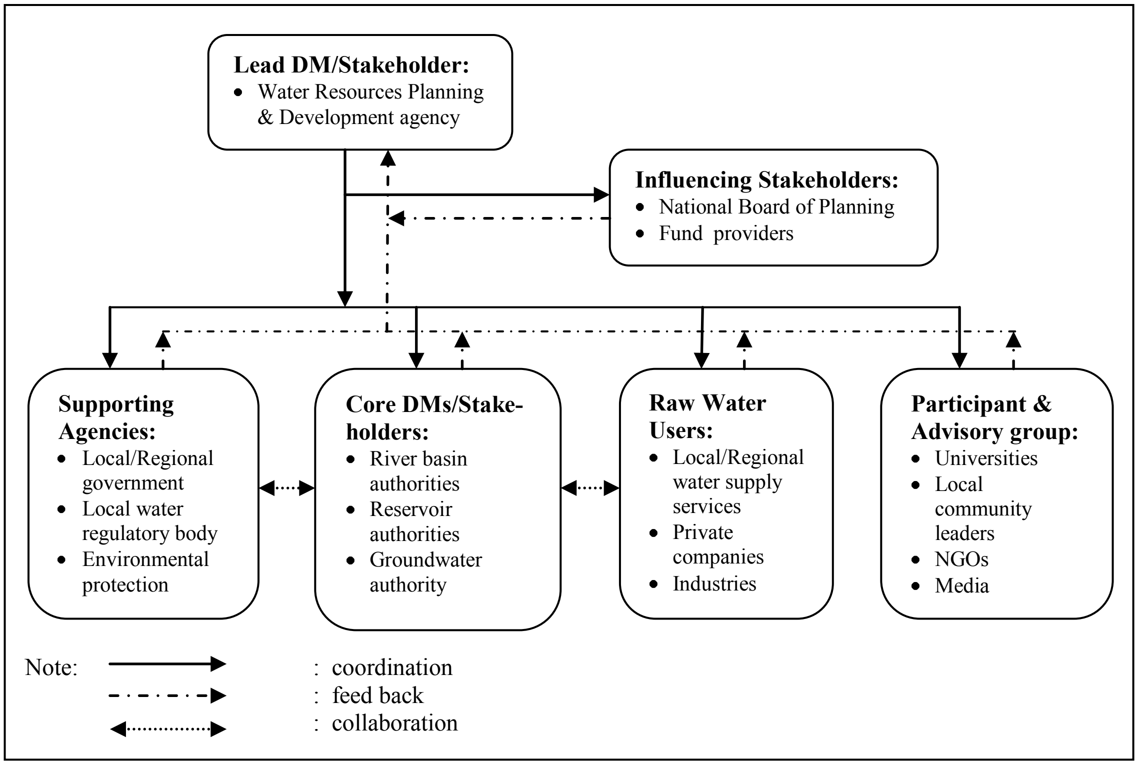

Figure 3.4. Institutional Arrangements for Raw Water Supply Development

The next step is to enhance stakeholder participation through workshops, consultation, surveys, and/or by inviting their representatives to be included in the planning and management structure. This process is important to gain participation, collaboration, and political will to support the planning and development process. Representatives from universities, media, relevant NGOs (Non-Government Organizations), and community leaders who are experienced or expert in raw water development can be invited as an advisory group to the management structure. Their knowledge and influences on public opinion are useful to management and could help with public education and to gain public approval of decision being made. With public approval and support, the implementation of planned actions is facilitated.

3.5. DSS of Integrated Decision-Making

The spreadsheet-based DSS of Integrated Decision-Making (IDM) model includes a general MCDA model and the Supply_sim model. The author made modifications to the MCDA model presented by Fontane and Arabi (2009) to fit the purposes of this study. The result of the DSS model is a ranking of best alternative actions. The general procedure to find the best option using the DSS model of IDM is explained in Appendix E.

The DSS model includes a matrix evaluation of alternatives of solutions or planned actions for raw water development versus criteria/sub-criteria to achieve the objectives. Criteria and sub-criteria are determined bases on the goals and strategies being set for raw water development. Input data for the matrix are results of analysis or assessment from many different aspects/viewpoints (e.g., technical, economics, environment, and social) for each alternative action. The matrix evaluation accommodates the concept of analyzing many aspects as an integrated whole system. The integrated presentation of the matrix evaluation with all of the assessments could help decision-makers to think systematically about the complex problem and to improve the quality of the decisions being made.

The DSS model also provides an interactive environment through a user interface that is aimed to help the decision-makers to find the better decisions. As the purpose of the DSS model is to solve "what-if " problems by representing their nature and applying scenario inputs, the DMs can change the inputs such as the scenario, criteria and the relative importance among criteria/sub-criteria to test different decisions. By dividing the DMs (i.e., stakeholders) into several decision-making groups, they can all participate in the decision-making process. Each group can change the relative importance among criteria to see the results in charts or graphical displays. Then the DMs can decide on the best action or solution that should be taken.

Through the DSS, a transparent decision-making process can be achieved to reduce the uncertainties and misinterpretations in communications and combining conflicting views. With a transparent process, the stakeholders can be assured that all are included in the process and that the process is fair. In this process, the leading stakeholders get mutual understanding and consensus among themselves and incentives to support the decisions being made. Without transparency, stakeholder support and commitment to the decision are difficult to achieve.

3.6. Elements of the DSS of IDM

The main elements of the DSS are alternative actions and programs, criteria/sub-criteria, matrix evaluation, the decision-making process, and the decision.

a. Criteria/Sub-criteria.

Selected measures that represent the objectives for raw water development are used as criteria and/or sub-criteria to evaluate all possible alternatives for development. Assessment results of performance of alternatives based on criteria/sub-criteria are presented in a matrix-evaluation format so that they can be analyzed as an integrated whole system.

b. Alternatives for Raw Water Development.

Alternatives for raw water development are based on the policies, objectives, and strategies. These will vary on a case-by-case basis and their details for this study are in Chapter 4.

c. ***Matrix Evaluation.***

Matrix evaluation accommodates different viewpoints of the integrated system. Performance assessments of alternatives versus criteria/sub-criteria are presented on the matrix and used in the subsequent MCDA. Performance assessment is based on the system analysis process (e.g., water allocation for each demand cluster, expert's judgment or logical assessment) for all sub-criteria.

d. Decision-Making Process.

The decision-making process is through the MCDA function of Integrated Decision-Making (IDM). All stakeholders participate to provide their viewpoints on the relative importance of the criteria to help rank the alternatives based on their viewpoints. The relative importance factors are input as a ratio of importance of a criterion as compared to the least important criterion. For example a relative importance factor = 2, means that the criterion considered it twice as important as the least important criterion. If all the relative important factors are equal to a value of one this means all the criteria are equally important. The largest allowable value of a relative importance factor considered in this study was 5. Once relative importance factors exceed a value of 4 or 5 then the mathematical impact of that factor becomes so large that it can effectively create a single criterion problem. The user inputs the relative importance of criteria through an "interface-page" in the DSS. The DSS computes and stores the weighted scores for each alternative for each of the five decision groups. This integrates the preferences of all the groups into the process of ranking the alternatives and also provides a sensitivity analysis relating the choice of decision influence groups to the ranking of the alternatives. The recommended ranking of the alternatives is determined based on the overall results, using descriptive statistics, such as average score and standard deviation, based on the combined ranking of all the groups (see Chapter 4).

e. Decision Result

Preliminary ranking is used to rank alternatives through MCDA and sensitivity analysis is used to test whether the ranking order is sensitive to change. Results from those two processes become the outputs of the DSS.

The result of the DSS process is a ranking of alternatives with supporting data. This result is used as a guide for the actions, projects or programs to be implemented and to document the process for possible future audits.

3.7. Supply_sim Model

The Supply_sim model is used within the DSS to calculate water allocation for each demand cluster. The author developed the spreadsheet model based on simulation and optimization concepts. The model applies the network flow simulation concept and optimizes supply and demand for each cluster by using the "Solver" tool of the spreadsheet. Details of the model, the calculation procedure, and the results are provided in Appendix C.

The model determines water allocations for each demand cluster, the percentage of demand that can be fulfilled, and the source of the raw water. The Solver tool helps optimize the flow by balancing the supplies among the demands. The constraints can be used to require that demands of particular clusters must be fulfilled at given levels, with appropriate trade-offs of shortages at other clusters.

The allocation for each cluster is used as data to assess sub-criteria on the DSS and to calculate the cost of planned reservoirs and conveyances.

3.8. Logical Assessment

Where there is a lack of data, logical assessment using inference or deductive logic is applied to evaluate the performance of alternatives. The method of logical assessment applied is based on the work of Pshenichny et. al. (2003). His application was focused on volcanology. It describes the relationships between statements or propositions what are expressed by narrative sentences using natural language. A statement is either true or false and these are logical values of statements. Verbal expressions such as “and”, “or”, “if…then”, “either…or” and others have the sense of logical connectives. The statements that do not include logical connectives are termed as “simple”, and those that do are termed as “compound statements”, or “compounds”. Compounds also are true or false. Their logical values are determined, first, by the logical values of elementary statements, and second, by the logical connectives between them.

Detailed explanation of the use of propositional logic for logical assessment is presented in Appendix D.

The work of Pshenichny (2003) and Spielthenner (2008) was used to check whether a decision is validated and supported by data and general concepts. It can be checked deductively from premises based on available data and concepts.

3.8.1. Example of Application of Logical Assessment

Logical assessment is used to estimate performance that is difficult to be graded by a number. An example of its use is illustrated here for the performance of the objective "reduction of land-subsidence rate." The grading used is "very-possible/ /possible/little-possible."

Statements or compound statements are denoted here:

h : Three causes of land-subsidence are geotectonic activity, load of structures, and groundwater abstraction. Land-subsidence by the load of structures tends to be local. The type caused by groundwater abstraction is likely to spread over a larger area because pressure disturbance within the groundwater tends to propagate easily.

i : Excessive groundwater abstraction in Jakarta is mostly caused by industries (including major hotels) due to lack of water supply provided.

j : Based on DGWR's (1992) study, up to one meter of land-subsidence occurred during 1978 – 1990 caused mostly by excessive groundwater abstraction. That period is when many industries were emerging in Jakarta.

k : Reduction of groundwater abstraction can reduce most of the rate of land-subsidence in Jakarta.

l : Reduction of groundwater abstraction can be achieved by:
- providing enough surface water supply with unit price lower than groundwater.
- having groundwater users convert to surface water by regulatory controls and taxes.

m : Level of reduction of the rate of land-subsidence depends on reduction of groundwater abstraction.

n : Industries and major hotels are the major users of abstracted groundwater.

o : Industries seek profit and will convert to surface water if it is available and cheaper than groundwater.

p : The Government provided enough surface water for the areas of land-subsidence in Jabotabek (i.e., Jakarta, Tanggerang, and Bekasi).

q : The Government applied strict regulation and high taxes on groundwater abstraction to make the unit price of groundwater more expensive than surface-water.

r : There will be a reduction in the rate of land-subsidence.

s : Assessment of performance of reduction of rate of land-subsidence is based on using the index: "very-possible/possible/little-possible".

t : Referring to "percentage of fulfillment" of surface water supply to the areas of land-subsidence of Jabotabek, the performance can be categorized as:

"very-possible" if "% of fulfillment" > 95% for areas with most impact;

"possible" if 95% ≤ "% of fulfillment" < 85% for areas with most impact; and

"little-possible" if "% of fulfillment" ≤ 85% for these areas.

u : Percentage of fulfillment of surface water supply in these areas for Alternative: A-1 is 84%; A-2 is 100%; A-3 is 100%; and A-4 is 100%.

v : Reduction of land-subsidence's rate for Alternative: A-1 is "little-possible"; A-2 is "very-possible"; A-3 is "very-possible"; and A-4 is "very-possible".

Based on statements above, we can check logical values (true or false) of the assumptions and formulate logical inferences that lead to the conclusion that the following statements are have true values: h, i, j, k, l, m, n, o, p, q, and r.

We can also note (inference 1) that statement k is implied from a combination of statements h, i and j. Also, inference 2 tells us that statement p is implied from a combination of statements k and l. Other inferences (3, 4 and 5) tell us that statement q is implied from a combination of statements k and l; statement r is implied from a combination of statements k, m, i, n, o, p and q; and statement v is implied from a combination of statements r, s, t and u.

The conclusion, based on logical assessment, is that the reduction of land-subsidence rate for Alternative: A-1 is "little-possible"; A-2 is "very-possible"; A-3 is "very-possible"; and A-4 is "very-possible".

Details of the use of logical assessment to estimate an alternative's performance with respect to other sub-criteria can be found in Appendix D.4.

CHAPTER 4

CASE STUDY:

INTEGRATED DECISION MAKING

FOR RAW WATER SUPPLY DEVELOPMENT IN JABOTABEK

4.1. Introduction

The study area (Figure 4-1) is the Jakarta Special District Capital (DKI Jakarta) and its surrounding areas. It includes river basins that are linked to the new development areas in the region.

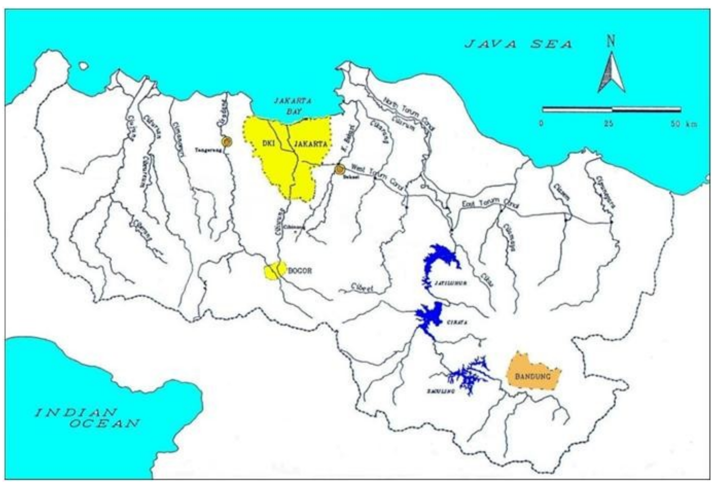

Figure 4.1. Location of Jabotabek, Indonesia

The raw water supply objectives are to fulfill projected water demands in 2025, to support regional economic growth and to reduce negative impacts such as raw water shortage, excessive groundwater abstraction and land-subsidence. Water-demand estimation is based on regional population and economic growth projections for Jabotabek in 2025 and presented in Table 4.1.

Table 4.1. Water demand clusters and its estimated water demand for 2025

Regional Area		Jabotabek						Outside Jabotabek	
Water Demand Cluster		Jkt	Tng	Bks	BoN	BoE	BoW	Ser	Kar
Area	*km2*	651	1397	1390	596	1304	1468	n.a.	n.a.
Population in 2005	*mil.*	11.7	3.5	3.0	1.6	3.5	1.1	2.7	3.0
Estimated Population in 2025	*mil.*	14.9	7.1	5.9	2.6	5.1	1.9	5.5	6.1
Estimated Water Demand in 2025	*m3/s*	42.1	22.2	16.2	5.4	10.8	3.3	17.3	18.1

(source : adapted from DGWR)

The available raw water sources are from groundwater, local medium-size rivers (e.g., Cisedane and Ciliwung), and the Jatiluhur reservoir on the Citarum river. Flow discharges of local small rivers are too low in the dry season and severely polluted and cannot be used for raw water supply. Although they are polluted in the downstream centers, the Cisedane and Ciliwung rivers are used as raw water supply due to their stable discharges. Groundwater sources are usually closed or inside the industry or private-sector areas. The Jatiluhur reservoir provides urban water for part of Jabotabek via the West Tarum Canal (WTC) and irrigation water for about 2,685 km2 of padi fields.

To fulfill future demand, additional reservoirs and conveyance systems were considered for the Ciujung, Cidurian and upper Cisedane rivers. The plan also includes an additional canal (Canal-2) or pipe to deliver water from Jatiluhur reservoir to Jakarta. Operational management to improve reservoir operation of three reservoirs (Jatiluhur, Cirata and Saguling) in the Citarum river system and raising the Cirata dam are considered to increase water availability from the Jatiluhur reservoir. More explanation about operational management for the Citarum River System is provided in the Appendix C.3.

Locations of available raw water sources for Jabotabek and potential locations to built reservoirs are shown in Figure A.1 in Appendix A. Tables of potential raw water sources and investment costs are also provided in Appendix A.

4.2. Land-subsidence and Seawater Intrusion

Excessive groundwater abstraction has caused severe environmental problems in the northern and central part of Jakarta, where many industrial areas are located. Topographic surveys have shown that during the period of 1978-1990 the land has subsided between 10-100 cm (DGWRD, 1992) (Figure 4-2). The most recent data (Wiwoho, 2010) stated that additional land-subsidence within 2002-2010 is between 11-116 cm, where the greatest is in the northern part of Jakarta, with spreading to the central and southern parts of Jakarta. However, no map is available.

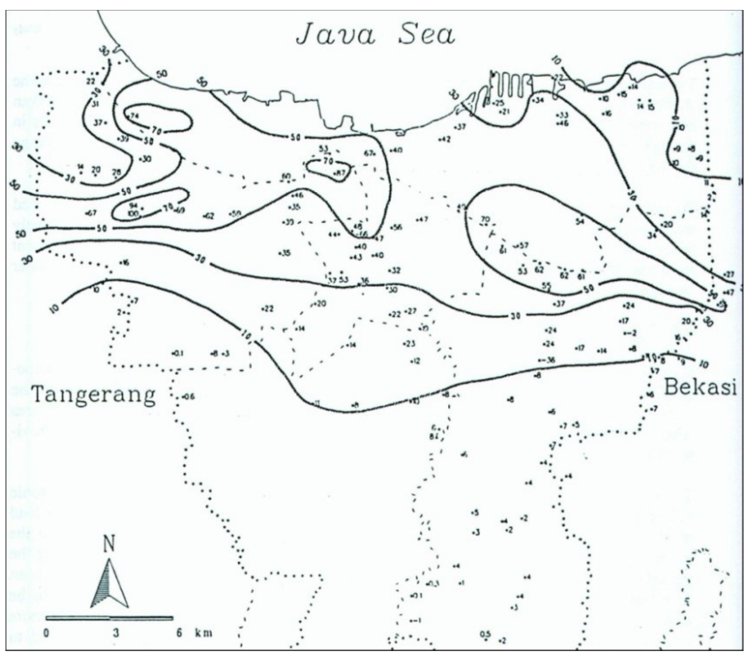

Figure 4.2. Map of observed of land-subsidence in Jakarta during 1978-1990
(source : DGWR)

Saline water has been found in shallow wells of the northern and central parts of Jakarta, but saline water in deep groundwater has been found only in the northern part of Jakarta. No data is available for saline water in other areas.

4.3. Procedure of Integrated Decision-Making Process

The procedure to apply the Integrated Decision-Making Process (IDM) for raw water supply development in Jabotabek includes:

- Applying the framework of IDM for the planning process.
- Applying the model of Institutional arrangements
- Applying the MCDA-based DSS for the decision process, that includes:
  - Strategies and identification of criteria/sub-criteria
  - Possible alternatives for raw water development.
  - Planned raw water allocation by the Supply_sim model, based on each alternative.
  - Assessment of each alternative's performance based on available data, planned raw water allocation and logical assessment. Decision-analysis using MCDA and participation of decision groups.

4.4. Strategies for Raw Water Development and the General Plan

Strategies for raw water supply development for Jabotabek include:

- Maximize use of the existing infrastructure of raw water supply sources.
- Provide enough surface raw water supply to reduce groundwater abstraction.
- Build additional raw water infrastructure so that supply for each demand-cluster is at least 80%.
- Apply zoning for groundwater abstraction to reduce further environmental damage and reduce or eliminate groundwater abstraction in the northern part of Jabotabek.
- Apply mixed raw water supply from surface water and groundwater for the southern part of Jabotabek.
- Minimize cost for building new infrastructure.
- Avoid political difficulties for implementation of the planned actions by trying to avoid new reservoirs that dislocate many people.

- Apply high tax on groundwater abstraction with the exception for local shallow water wells.
- Increase water fee (tariff) and apply cross-subsidy to help the poor urban people.

The general plan to provide raw water is presented in Figure 4.3.

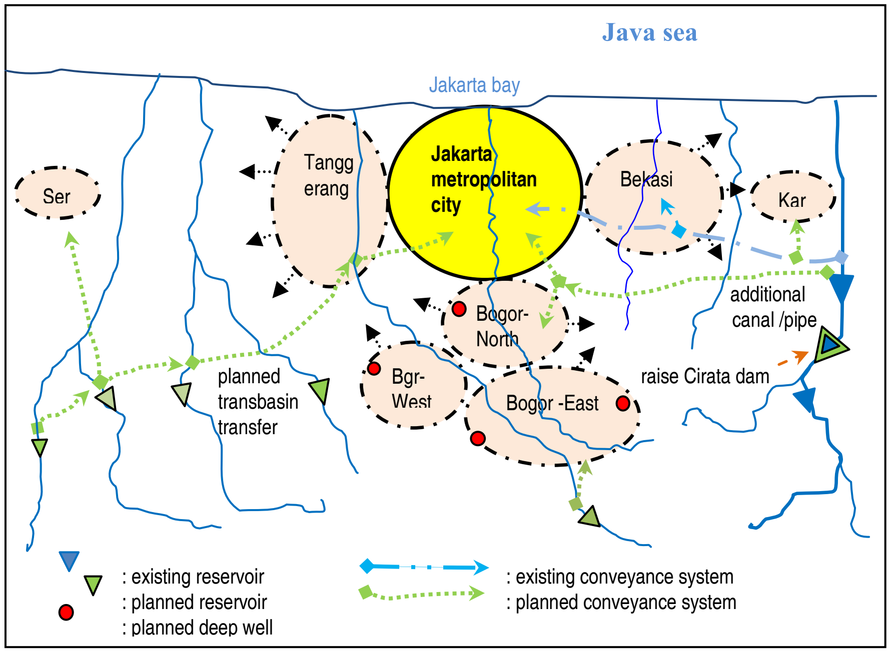

Figure 4.3. General plan of all possible alternatives of raw water supply developments for Jabotabek

This plan was used to determine the alternatives or scenarios that align with the strategies for raw water development. The alternatives are then analyzed through the DSS to identify the best alternatives or planned actions.

The following alternatives for Jabotabek raw water supply development were configured to demonstrate how the DSS might be used:

A-1: Minimum investment cost:
Build a minimum set of new reservoirs to provide surface water and balance the allocation of water.
Specific actions: Improve reservoir management in the Citarum river system to maximize water use, build additional canals and pipes to carry more water. In

the west, build the Karian reservoir, its conveyance system, and use all available water from the rivers.

A-2: Eliminate groundwater abstraction in areas of land-subsidence:
Fulfill water demands in area of land-subsidence (i.e., Jakarta, Tanggerang and Bekasi) from surface water and build additional reservoirs that require little dislocation.
Specific actions: Maximize the use of water from the Citarum river system and build additional canals and pipes in the east. In the west, build the Karian, Pasirkopo, and Cilawang reservoirs and their conveyance systems.

A-3: Use groundwater from selected zones to add more water supply:
Use groundwater up to maximum permissible to add supply, but only in the zones with no land-subsidence.
Specific actions: Use deep groundwater from the south zone (i.e., Bogor areas) to add more supply of water. Other planned actions are the same as in alternative A-2.

A-4: Fulfill all water demands from all possible resources:
Build more reservoirs to fulfill all water demand but only those with little dislocation.
Specific actions: The same as in alternative A-3 with the addition of building the Genteng reservoir in the south.

4.5. Criteria/Sub-criteria

To find the best alternative, all alternatives are evaluated versus criteria/sub-criteria in the matrix evaluation of the MCDA.

The criteria/sub-criteria and their objectives are (Min and Max mean to minimize or maximize):

1. Costs:
   - (Min) Construction cost for additional infrastructure.
   - (Min) Land acquisition cost (consider issues such as need to relocate people or build in urban centers).
   - (Min) Infrastructure O & M cost.
   - (Min) Water treatment O & M cost (poor quality of raw water will increase cost and fees for consumers).
   - (Min) Watershed O & M cost (cost is to maintain and protect watersheds from deterioration).

2. Fulfill Water Demands:
- (Max) Surface raw-water supply provided (m3/s).
- (Max) Reliability of water supply source.
- (Max) Irrigation water from new reservoirs.
- (Max) Average raw water quality.

3. Environmental Impacts:
- (Max) Reduction of the land-subsidence rate. *
- (Max) Reduction of the seawater intrusion. *
- (Max) Reduce spread of GW pollution. *
- (Min) Ecological impact due to trans-basin water transfer. *

4. Social & Political Issues:
- (Min) Number of people to relocate.
- (Max) Reduce health-risk to poor. *
- (Max) Available water for poor urban people.
- (Min) Political difficulties in land acquisition (Consider speculation when public becomes aware of land acquisition proposals)

5. Development & Economic growth:
- (Max) Employment opportunity.
- (Max) Recreation from new built reservoirs.
- (Max) Support economic growth.
- (Max) Support regional development.
- (Max) Support sustainability of water quantity.

Note: * For the case study these ratings were estimated since data were not available.

4.6. Decision Influence Groups

The DMs/stake-holders participate by choosing the relative importance factors (which are converted to relative weights) for the criteria and sub-criteria based on their viewpoint. Five potential decision groups were used in the case study:

- **G1** - This group is composed of agencies that provide funds for raw water supply. Their viewpoints have priority on minimizing investment cost, fulfilling the minimum demand, and supporting development and economic growth.

- **G2** - This group is composed of agencies responsible for O & M of raw water infrastructure. Their viewpoints have priority on minimizing O & M cost, fulfilling demand, and supporting development and economic growth.

- **G3** - This group is composed of the raw water users (water supply service agency/company, industry, commercial). Their viewpoints have priority on fulfilling the demand, and minimizing O & M cost since that will mean lower water fees.

- **G4** - This group is composed of agencies or parties concerned about the environment. Their viewpoints have priority on preventing negative impacts on the environment.

- **G5** - This group is composed of agencies or parties such as non-governmental organizations that represent public opinion and general societal concerns. Their viewpoints have priority on preventing negative impacts on society and fulfilling water demand, especially for the poor urban people.

4.7. Results of the DSS of IDM Model

4.7.1. Result of Supply_sim Model

A layout of raw water network flows is established based on the location of raw water sources (including the existing infrastructure) and location of water demand clusters. Based on the network flow as shown in Figure 4.4., the water supply allocation for each demand cluster is calculated using the Supply_sim model which considers:

- The purpose of each alternative and the raw water development strategies.
- Annual source of supply from all available raw surface water and groundwater sources
- Estimated annual water demands for year 2025 as targets to be achieved.

Water demand and water supply in the model represent the average annual flow discharge for each cluster in m^3/s (1 m^3/s = 22.8 mg/d). The result of the water allocation is used to determine the need to build a particular reservoir with its associated conveyance system. Flow discharges in the network from the Supply_sim model are used to determine the capacity of the conveyance system.

New reservoirs are considered for urban-water first and then for irrigation water, if additional supply is available. Their design capacities are determined based on the hydrologic system, topography, number of people to be relocated, and construction cost. The Supply_sim model only determines whether there is a need to build a reservoir. The capacity of the reservoir is determined by the reservoir designer.

Figure 4.4. shows the layout of raw water network flow for Jabotabek raw water development.

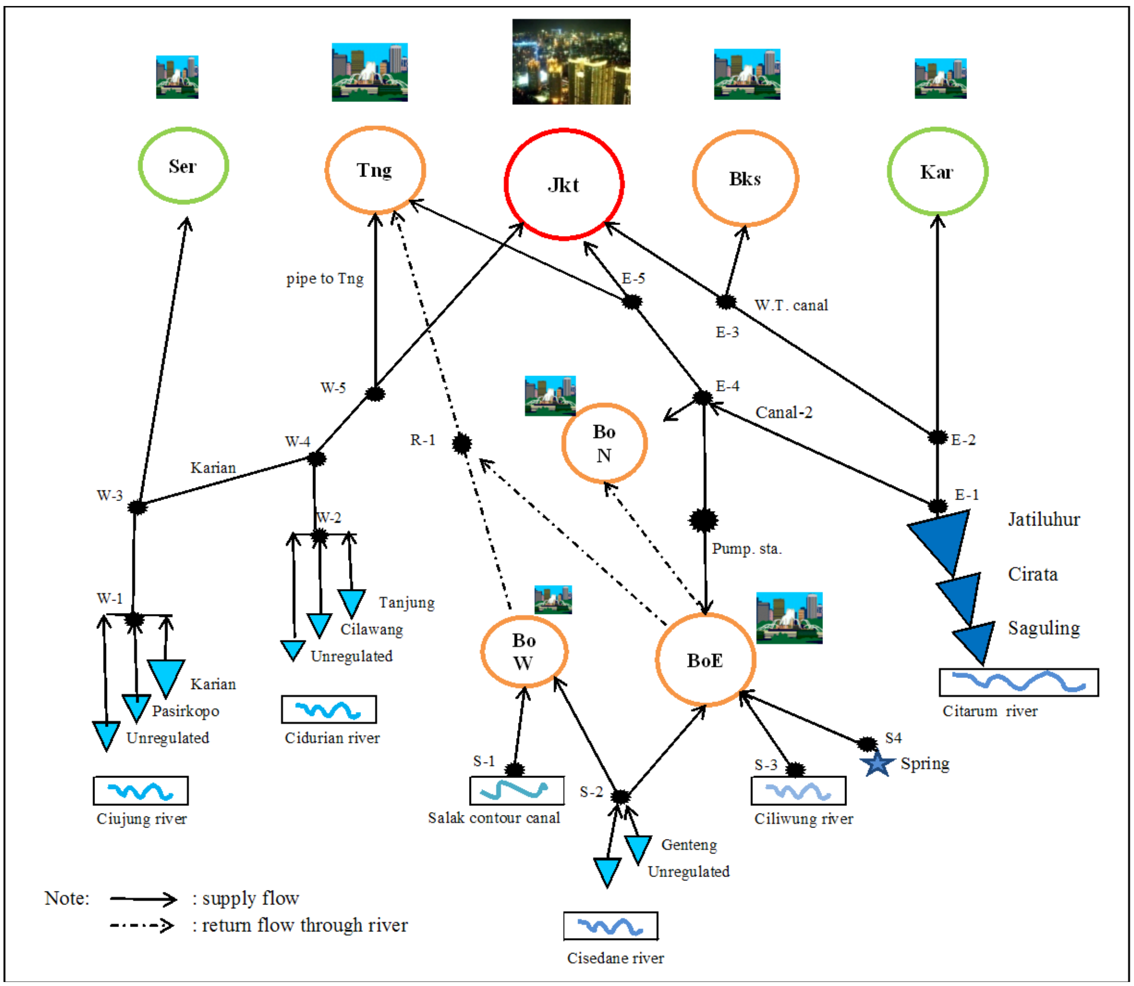

Figure 4.4. Layout of raw water network flow for Jabotabek

As an illustration, Table 4.2. shows the results of Supply_sim calculations for alternative A-3.

Table 4.2. Result of water supply allocation for alternative A-3

Supply_sim Model
Developed by: Edy A. Soentoro

Raw Water Supply Allocation

Urban center	Serang Ser	Tanggerang Tng	Jakarta Jkt	Bekasi Bks	Karawang Kar	Bogor North BoN	Bogor East BoE	Bogor West BoW	Total
Water demand	17.3	22.2	42.1	16.2	18.1	5.4	10.8	3.3	135.40
Surface water supply	15.05	22.20	42.10	16.20	16.02	3.78	7.56	2.00	124.90
Groundwater supply	0.00	0.00	0.00	0.00	0.00	1.00	2.00	1.00	4.00
Total water supply	15.05	22.20	42.10	16.20	16.02	4.78	9.56	3.00	128.90
Supply /demand (%)	*87.0*	*100.0*	*100.0*	*100.0*	*88.5*	*88.5*	*88.5*	*90.9*	*95.2*

Source of raw water supply :		Surface raw water					Groundwater	
(from actual release)		West-1	West-2	East-1	South	Retr. flow	GW	Total
	(in m3/s)	31.00	7.00	75.00	5.90	6.00	4.00	128.90

Fraction of flow	w3-sr/w1-3	w5-tng/w4-5	e1-2/e1	e2-3/e12	e3-jkt/e2-3	e4-5/e1-4	e4-bo-n/e4-5	e5-jkt/e4-5	s2-boe/s2
Fract. estimation	0.486	0.000	0.430	0.503	0.000	0.873	0.042	0.513	1.000

River	Reservoir	Max. Release	Act. Release	Canal	Flows	Canal	Flows	Grounwater pumping:	
Ciujung:	Karian	15	15	**West :**		**East :**		max /location	
	Pasirkopo	7	7	W1-W3	31.00	E1-E2	32.22	(m3/s):	1
	Unregulated	9	9	W3-Ser	15.05	E2-Kar	16.02	(mgd):	22.83
Cidurian:	Tanjung	7	0	W3-W4	15.95	E2-E3	16.20	**City/Area:**	
	Cilawang	4	4	W2-W4	7.00	E3-Bks	16.20	**Bo-N :**	
	Unregulated	3	3	W4-W5	22.95	E3-Jkt	0.00	# of location:	1
Citarum:	Jatiluhur	50	50	W5-Tng	0.00	E1-E4	42.78	max (m3/s):	1
	* flow prediction	10	10	W5-Jkt	22.95	E4-E5	37.35	actual (m3/s):	1
	* drought mngmt.	10	10			E4-BoN	1.78	**Bo-E :**	
	* on demand irrigation	5	5	**South :**		E4-BoSE	3.66	# of location:	2
	* raised Cirata dam	15	0	S1-BoW	2	E5-Jkt	19.15	max (m3/s):	2
Cisedane:	Genteng	6.5	0	S2-BoW	0.00	E5-Tng	18.20	actual (m3/s):	2
	Unregulated	1.5	1.5	S2-BoE	1.50			**Bo-W :**	
	Salak canal	2	2	S3-BoE	2.00	**Return flow:**		# of location:	1
	downst.flow-W	3	3	S4-BoE	0.40	BoE-BoN	2.00	max (m3/s):	1
	downst.flow-E	1	1			BoE-R1	1.00	actual (m3/s):	1
Ciliwung :	upstream flow	2	2			BoW-R1	3.00		
	spring	0.4	0.4			R1-Tng	4.00		
	downst.flow	2	2						

Instruction : [green cell] : decide water demands, actual release from reservoirs and groundwater wells
actual release from a reservoir will mean that the reservoir should be built or is ready there
[blue cell] : enter the fraction estimation to find the best result

Note : Jatiluhur-Cirata-Saguling (E1) are the only existing reservoirs in the network right now, the others are need to be built.
Present West Tarum canal has max. capacity 24 m3/s, other conveyance systems are need to be built or through rivers

As shown in Table 4.2, supply for the Jakarta, Tanggerang and Bekasi demand clusters is 100%, and other the demand clusters range between 87-91%. Column 3 (Max.Release) shows the maximum release discharge of each reservoir and column 4 (Act. Release) shows the actual release discharge, which also indicates where the water comes from to supply the network flow. If the actual release discharge is zero for a particular reservoir, there is no need to build that reservoir. Column 10 shows the maximum available permitted and the actual groundwater abstraction of each location or area.

The information indicates which reservoirs and conveyance systems should be built, including their capacities and costs. Flow discharges (the columns "Canal" and "Flow") show needed conveyance capacities. The percentage of water demand/supply leads to the assessment for other sub-criteria (e.g., reliability of water supply source) in the evaluation matrix. Results of the simulation output for the other alternatives are presented in Appendix B.1.

4.7.2. Matrix Evaluation

The matrix evaluation (Table 4.3) of the performance of alternatives in the DSS is used as input data for the MCDA to analyze and to rank the alternatives based on selected MCDA techniques. Since the criteria/sub-criteria represent different objectives (economic, environment and social), using the MCDA enables the consideration of different objectives in an integrated system.

To determine the performance of each alternative, several steps are required:

1. Determine the water supply allocation to each demand cluster, the percentages of water demands to be fulfilled, and the water sources that should be used.
2. Based on the water allocation, calculate the cost of supplying the water using data about reservoirs, land acquisition, and conveyance systems.
3. Calculate the performance of all alternatives. Use available data, the results of the simulation of the water supply allocation and finally logical assessment where data are incomplete.

Table 4.3. Matrix evaluation for Jabotabek raw water development

Data for Jabotabek Raw Water Supply Development

Criteria : Sub-Criteria :	Max/Min	A-1	A-2	A-3	A-4
		ALTERNATIVES			
1. Cost :					
Construction cost, surface & groundwater (bil Rp.)	Min	6916	8496	9518	11608
Land acquisition cost (billion Rp.)	Min	2809	4480	4488	4732
Infrastructure's O & M cost (billion Rp./yr)	Min	79	103	154	181
Water treatment's O & M cost (billion Rp./yr)	Min	541	593	602	738
Cost for watershed O & M (billion Rp./yr)	Min	72	92	92	104
2. Fulfill the Water Demands :					
Total raw-water supply provided (m3/s)	Max	113.9	124.9	128.9	135.4
Reliability of water supply source	Max	Fair	Good	Very Good	Excellent
Irrigation water from new built reservoir	Max	Some	Significant	Significant	Significant
Average raw water quality	Max	Good	Good	Very good	Very good
Sub-Crit -5,2					
3. Environmental Impacts :					
Reduce rate of land-subsidence *	Max	Little Possible	Very Possible	Very Possible	Very Possible
Reduce sea-water intrusion *	Max	Little Possible	Possible	Very Possible	Very Possible
Reduce spread of groundwater pollution *	Max	Little Possible	Possible	Very Possible	Very Possible
Ecological impact due to transbasin transfer *	Min	Some-2	Many	Many	Many
Sub-Crit -5,3					
4. Social & Political Issues :					
Number of people need to be relocated	Min	8700	14900	14900	16700
Reduce of health-risk of the poor *	Max	Little Possible	Possible	Very Possible	Very Possible
Available water for the poor urban people	Max	Fair	Very Good	Excellent	Excellent
Political difficulties *	Min	Few	Some-2	Some-2	Many
Sub-Crit -5,4					
5. Development & Economic growth :					
Employment opportunity *	Max	Good	Very Good	Excellent	Excellent
Recreation from new built reservoir	Max	Not Significant	Some	Some	Significant
Support economic growth *	Max	Fair	Good	Very Good	Excellent
Support regional development *	Max	Fair	Good	Very Good	Excellent
Support sustainability of water quantity *	Max	Not Significant	Some	Significant	Significant

Note: * : based on logical estimation, no data available.

A benefit of presenting the results in a matrix is that the alternatives can be readily compared. Even though the actual data has not yet been converted to a common rating scale, it is apparent that some alternatives will perform well for some criteria but poorly in others. For example, the more expensive options will provide better environmental and social conditions. This means that tradeoffs and compromises among the objectives will need to be considered.

4.7.3. Preliminary Ranking Result

An example of the preliminary ranking of alternatives through MCDA is presented. Referring to the right top in Figure 4.5, you see the method chosen for MCDA analysis with a dark blue background, in this example the Compromise Programming (CP) method with p =2 (the L2 norm). This approach scales the rating based on the distance of an alternative from the best solution divided by the range between the best and worst solutions. The power of two (p = 2) gives more weight to the better rankings. Note that the compromise programming metric gives a rating that ranges between 0 and 1 with 1 being the best solution.

In the first table box (from the top-left of the figure), you see the results from the method chosen and the decision making group chosen, which is as indicated by black dot on top of G5. The table shows the relative importance factors chosen by the decision making groups for the main criteria. Group 5 was the decision influence group that had its highest priority on social issues and this is reflected in the assignment of a relative importance factor of 5 for this main criterion. The first chart "Alternative comparison for G5" plots result from the first table box based on the viewpoint of decision-making group G5. The chart shows that the group that has high priority on social issues (G5) chose alternative A4 as ranking number one. If the black dot on top of G5 in the second table box is moved to any other decision influence group, the content in the first table box and the first chart will change accordingly.

The third table box shows the result of combining decision-making groups (i.e., from G1 to G5) from one method (i.e., CP). The overall ranking is illustrated from the average score, and shows in the table and in the second column-chart. The standard

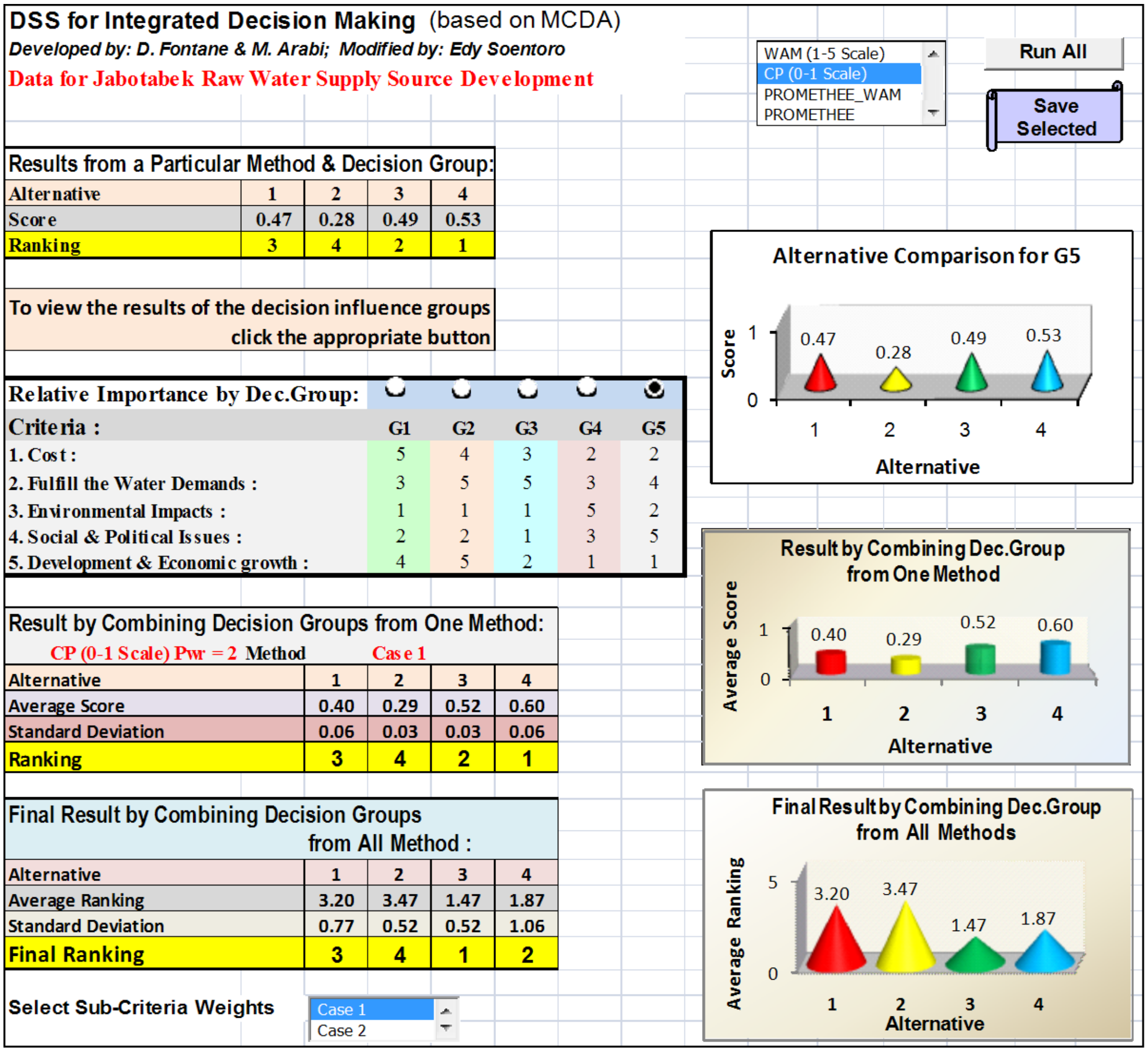

Figure 4.5. Result of DSS for IDM based on CP method with p=2

deviation is used to illustrate the variability of the ranking. Since all the results are stored, any descriptive statistical measure can be used. Depending upon the results, the median or mode might be more appropriate than the average. The average value is used in the case study; however, it is only an example. The fourth table box shows the result by combining the ratings for each decision-making group using each of the three MCDA methods (i.e., WAM, CP, and Promethee_WAM). The overall ranking order is determined based on the average values of the ranks, because the methods used different scales for scoring (i.e., 1 to 5, 0 to 1, and -1 to +1). The third column-chart shows the final ranking order from the fourth table box.

From Figure 4.5, we see that ranking order from the best to the worst is alternative A-4 → A-3 → A-2 → A-1 (G5; CP method). By combining results for all the decision influence groups of G1 to G5 and all MCDA methods the final ranking order is A-3→ A-4 → A-2 → A-1. The best two alternatives (A-3 and A-4) are then studied more closely to determine the sensitivity of their ranking to the values of their ratings. Results of the DSS with the WAM and Promethee_WAM methods are provided in Appendix B.2.1.

4.7.4. Sensitivity Analysis

Sensitivity analysis is used to test whether the ranking order, is stable or sensitive to change. By using all the decision influence groups and all the provided MCDA methods, the results have already considered a first analysis of the sensitivity of the rankings to decision group and method. The first analysis was done by observing the average score, ranking and standard deviation of the ranking order. The second analysis used the best two alternatives from the first analysis and repeated the MCDA process using different rating scales. If those alternatives are sensitive to particular sub-criteria with different rating scales, the ranking order between them will be different from the initial ranking.

Based on the initial ranking results of each method (see figure B.2.1.1. to B.2.1.3. in appendix B.2.1.), we see that the average score of each alternative (i.e., from combination of G1 to G5) is such that the higher ranked alternatives are more than a standard deviation of the score better than the lower ranked alternatives. This gives confidence in the selection of the top ranked alternatives. If the average scores differed by less than the standard deviation this would indicate that the alternatives are practically equal in rank. The large difference in average scores occurs in the results combing all MCDA methods, so the consideration of the standard deviation does not change the overall ranking order. The initial results show alternative A-3 and A-4 to have the best ranks. These alternatives were then tested in a second sensitivity analysis process.

The second sensitivity analysis was carried out by changing rating scales from Rating-(1) to Rating-(2) to give more significant differences among the alternative's performance on particular sub-criteria, see Table 4.4. below:

Criteria:		Alternatives:	
Sub Criteria:	Max/Min	A-3	A-4
1. Cost :			
Construction cost, surface & groundwater (bil Rp.)	Min	9518	11608
Land acquisition cost (billion Rp.)	Min	4488	4732
Infrastructure's O & M cost (billion Rp./yr)	Min	154	181
Water treatment's O & M cost (billion Rp./yr)	Min	602	738
Cost for watershed O & M (billion Rp./yr)	Min	92	104
2. Fulfill the Water Demands :			
Total raw-water supply provided (m3/s)	Max	128.9	135.4
Reliability of water supply source	Max	**Very Good**	**Excellent**
Irrigation water from new built reservoir	Max	Significant	Significant
Average raw water quality	Max	Very good	Very good
Sub-Crit -5,2			
3. Environmental Impacts :			
Reduce land-subsidence's rate *	Max	Very Possible	Very Possible
Reduce sea-water intrusion *	Max	Very Possible	Very Possible
Reduce spread of groundwater pollution *	Max	Very Possible	Very Possible
Ecological impact due to transbasin transfer *	Min	Many	Many
Sub-Crit -5,3			
4. Social & Political Issues :			
Number of people need to be relocated	Min	14900	16700
Reduce of health-risk of the poor *	Max	Very Possible	Very Possible
Available water for the poor urban people	Max	Excellent	Excellent
Political difficulties *	Min	**Some-2**	**Many**
Sub-Crit -5,4			
5. Development & Economic growth :			
Employment opportunity *	Max	Excellent	Excellent
Recreation from new built reservoir	Max	**Some**	**Significant**
Support economic growth *	Max	**Very Good**	**Excellent**
Support regional development *	Max	**Very Good**	**Excellent**
Support sustainability of water quantity *	Max	Significant	Significant

Scales :		
Word	Rating (1)	Rating (2)
Excellent	5	5
Very Good	4	3
Good	3	2
Fair	2	1.5
Bad	1	1
Significant	5	5
Some	3	2
Not Significant	1	1
Very Possible	5	5
Possible	3	3
Little Possible	1	1
Few	5	5
Some-2	3	4
Many	1	1

Table 4.4. Changing Rating Scale for Sensitivity Analysis

As an example, by changing the rating scale on "few/some-2/many" of the assessment of "Political difficulties" sub-criterion we obtain different results on the scores for alternatives A-3 and A-4 on that sub-criterion. The ranking order may still be the same or change depending on the relative importance of the pertinent sub-criteria and criteria whose rating scale being changed. Figure 4.6. shows how the ranking order based on G5 and the combination of G1 to G5 change to indicate that A-3 is better than A-4. The result of combining all methods is the same as the initial ranking. Observing the average ranking and standard deviation (in Figures 4.5. and 4.6.) also supports the conclusion that A-3 is the better alternative.

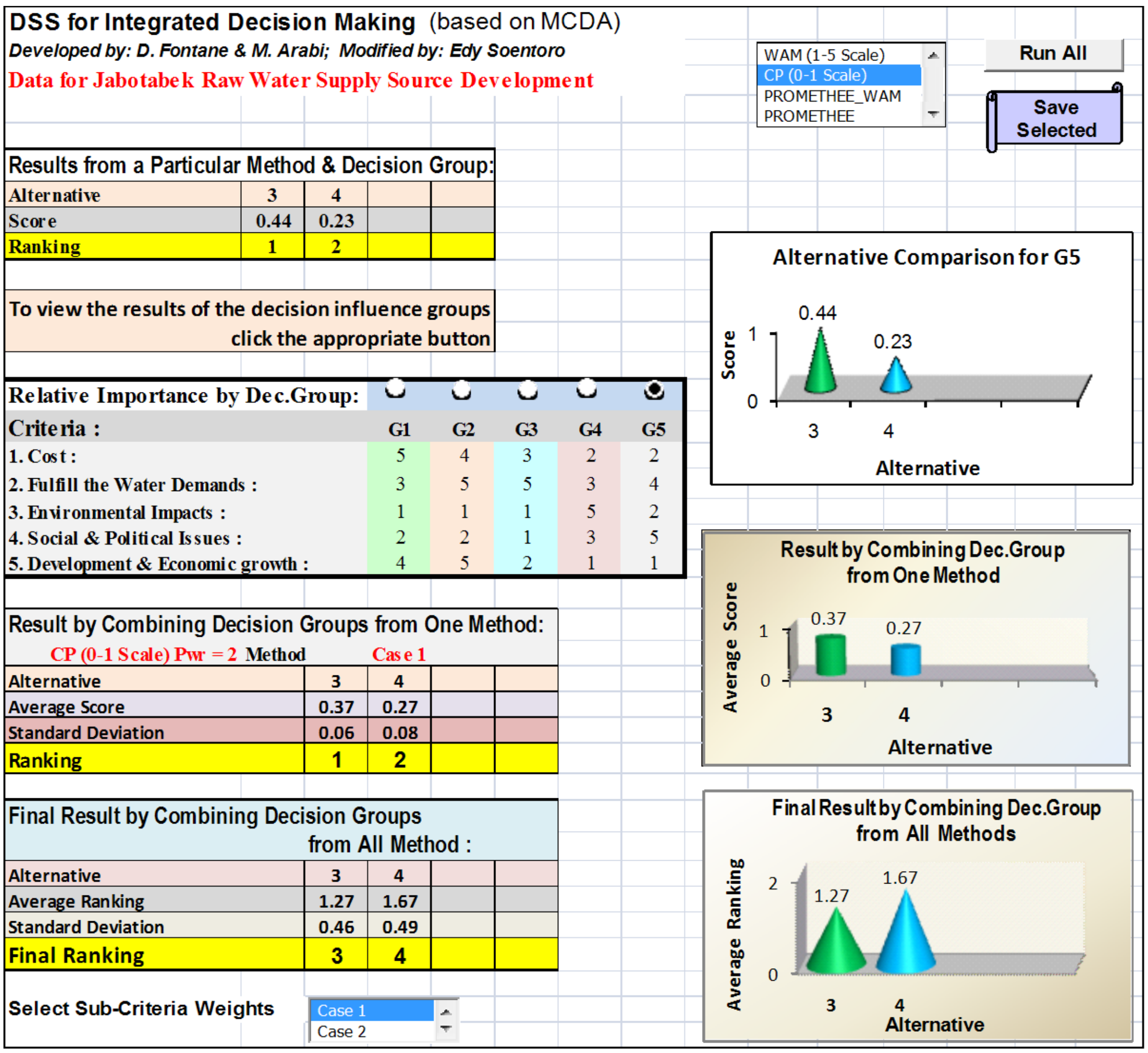

Figure 4.6. Result of sensitivity analysis based on CP method with p=2

The sensitivity analysis by changing the rating scales can be used with the WAM and CP methods, since these methods are value-based method and the rating is based on the actual value of performance. Using the Promethee method will not change the ranking order because this is an outranking based method. The ranking is based on preference, whether performance of one alternative is better than that of another alternative without considering the magnitude of the performance difference.

Additional sensitivity analysis might be done by changing the relative importance factors of criteria. The decision-making groups (G1 to G5) could change the relative importance factors in the DSS and the MCDA could be re-run. The value of conducting sensitivity analysis is that it shows the stability of the overall ranking under a range of input conditions.

The conclusion that Alternative A-3 is the best alternative for this case study is a reasonable answer based upon the ratings and relative importance factors (weights) used. Using the initial ranking results with four alternatives as the base of this analysis, A-3 is ranked first in 8 of 15 analyses based on each decision group from all methods. A-3 is ranked first in all of the WAM methods and in 3 of 5 of the Promethee_WAM method results. With the CP method (with p=2), A-3 is ranked second with slightly different scores. If the CP method with p=1 is applied, A-3 becomes ranked first for all decision groups G1 to G5.

Perhaps most importantly, alternatives 3 and 4 are logical choices based upon the information in the MCDA matrix should in Table 4.4. While these two alternatives are the most expensive, they are the better alternatives with respect to all the other criteria. Alternative A-3 is less expensive compared to A-4; however, it is almost as good with respect to all the other criteria. While this conclusion may have been reached without the MCDA, the MCDA analysis helped to make this conclusion much more obvious. A next step might then be to develop new alternatives perhaps combining elements of alternatives 3 and 4 and repeating the entire process until a set of alternatives are found that the decision groups can reach an agreement upon.

CHAPTER 5

RESEARCH FINDINGS AND ANALYSIS

5.1. Technical Analysis

5.1.1. The DSS of IDM Model

The results of applying the DSS of Integrated Decision Making (IDM) model in this study can be listed as follows:

1. The goal of the decision-making process is to produce the best outcome that is acceptable to all the DMs/stakeholders through consensus. As a tool to produce the best outcome, the DSS model for IDM could accommodate the concept of analyzing many different viewpoints as one integrated whole system. Matrix evaluation within the DSS could help the DMs to think systematically about complex decision problems and to improve the quality of the resulting decision. MCDA method could find the best outcome from many alternatives/scenarios to solve the problem.
2. As a tool to reach a consensus, the DSS model for IDM could provide decision-making process that is transparent, easy to understand, and give all the DMs the chance to participate in the decision process. The transparent process could reduce a possible misinterpretation in both communications and combining conflicting viewpoints. With the transparent process, the stakeholders can be assured of that the process is fair, and all of them are included in the decision process. A transparent

process and the feeling of being included in the decision-making process are important factors to gain commitment of the DMs for the decision being made.

5.1.2. Supply_sim Model

The Supply_sim model provides a potential water supply allocation for each alternative and evaluates the development strategies.

The related water development strategies include:

- Provide enough surface raw water supply to reduce groundwater abstraction.
- Reduce or no groundwater abstraction in northern part of Jabotabek.
- Supply at least 80% of the demand for each demand-cluster.
- Apply mixed raw water supply from surface and groundwater for the southern part of Jabotabek.
- Try to avoid build new reservoirs that need to move a lot of people.

Table 5.1. Water allocation for each demand cluster based on Alternative

Result of raw water allocation from Suppy_sim model																			
Urban center		Serang Ser		Tanggerang Tng		Jakarta Jkt		Bekasi Bks		Karawang Kar		Bogor North BoN		Bogor East BoE		Bogor West BoW		Total	
Supply/Demand			Sp/D		Sp/D		Sp/D		Sp/D		Sp/D		Sp/D		Sp/D		Sp/D		Sp/D
unit		m3/s	%	m3/s	%	m3/s	%	m3/s	%	m3/s	%	m3/s	%	m3/s	%	m3/s	%	m3/s	%
Water demand		17.3		22.2		42.1		16.2		18.1		5.4		10.8		3.3		135.40	
Water supply for each Alternative:																			
A-1	Surface	14.61		18.74		35.36		13.61		15.20		4.54		9.07		2.77		113.90	
	Ground	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
	Total	14.61	**84**	18.74	**84**	35.36	**84**	13.61	**84**	15.20	**84**	4.54	**84**	9.07	**84**	2.77	**84**	113.90	**84**
A-2	Surface	13.84		22.20		42.10		16.20		14.84		4.40		8.67		2.64		124.90	
	Ground	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
	Total	13.84	**80**	22.20	**100**	42.10	**100**	16.20	**100**	14.84	**82**	4.40	**82**	8.67	**80**	2.64	**80**	124.90	**92**
A-3	Surface	15.05		22.20		42.10		16.20		16.02		3.78		7.56		2.00		124.90	
	Ground	0.00		0.00		0.00		0.00		0.00		1.00		2.00		1.00		4.00	
	Total	15.05	**87**	22.20	**100**	42.10	**100**	16.20	**100**	16.02	**88**	4.78	**88**	9.56	**88**	3.00	**91**	128.90	**95**
A-4	Surface	17.30		22.20		42.10		16.20		18.10		4.40		8.80		2.30		131.40	
	Ground	0.00		0.00		0.00		0.00		0.00		1.00		2.00		1.00		4.00	
	Total	17.30	**100**	22.20	**100**	42.10	**100**	16.20	**100**	18.10	**100**	5.40	**100**	10.80	**100**	3.30	**100**	135.40	**100**

The results for each Alternative are:

A-1: Minimum investment cost; build new reservoirs as minimum as possible to provide more surface raw water, and spread the water allocation to the same percentage of water demand.

Result: Build one reservoir, and the supply/demand for each demand cluster is 84%.

A-2: Eliminate groundwater abstraction in areas of land-subsidence; fulfill water demands for Jakarta, Tanggerang and Bekasi from surface water.
Result: Supply/demand for Jakarta, Tanggerang and Bekasi is 100% each, and for the other demand cluster is between 80 to 82% each.

A-3: Use groundwater up to maximum available permitted to add more supply of water, but only in the zones with no land-subsidence has been found (i.e., Bogor area).
Result: Supply/demand for Jakarta, Tanggerang and Bekasi is still 100% each, and for the other demand cluster increase up to 91% each.

A-4: Fulfill all water demands from all possible resources.
Result: Build one more reservoir with the least people need to be moved, and supply/demand for all demand clusters is 100% each.

From the result above, it shows that Supply_sim model could allocate water supply as the purpose of each alternative and the development strategies. The results include the planned water supply allocation for each demand cluster, the percentage of water demand that can be fulfilled, and where the raw water comes from. This information is used to calculate the costs (e.g., construction of reservoir, conveyance system and land acquisition), and as input data for logical assessment.

5.2. Institutional Analysis

This section presents an institutional analysis of the case study. The outlines of the institutional model were presented previously in Section 3.4.

The authority that water resources are in the public domain is from the Indonesian Constitution of 1945, so the decision-makers and stakeholders of raw water supply development are mostly government agencies. Article 3, point 3 of the Constitution states: "… w*ater, land and all natural resources are controlled and administered by the State, and it must be used for the welfare of the people."*

The model showed an ideal situation of four main groups that participate in raw water decisions: the water management authorities, the supporting and regulatory government agencies, the raw water users, and the stakeholders at the level of the agencies and water users. While such a high-level conceptual model of the institutional arrangements applies in Indonesia, the details are flawed.

Management of water by the government places tight controls on the flexibility for change. The government-dominated water management institutions for raw water development are fragmented and overlapping in authority and programs, their roles, responsibilities and coordination are poorly defined, and there are limited tools and human resources to implement the integrated decision-making concept. Law enforcement for violations related to water pollution and inappropriate land-use change is weak. The decision-making process is not transparent yet and public involvement does not have any role in the decision process. Public interest is only represented by the relevant government agencies.

As an example of fragmented or overlapping authority and programs, the Citarum river basin authority is responsible for O & M of infrastructure in its river basin, but O & M of three large reservoirs in the basin are carried out by other agencies. These are the Saguling and Cirata reservoirs, which are maintained by PLN (State Electrical Enterprise) and the Jatiluhur reservoir, where O&M is by the Jatiluhur authority. The government assesses that Jatiluhur is an important raw water supply for Jakarta and irrigation water for large padi fields, so a special agency is needed to manage it.

Therefore, showing river basin authorities in a box on the institutional arrangements is overly-simple, because it is necessary to explain the interacting and conflicting roles among them.

As another example of fragmented or overlapping authority and programs, there are conflicts at the national government level. Whereas water supply development for rural areas is coordinated under the Directorate General of Human Settlements (DGHS) in the Ministry of Public Works, for regional raw water supply developments such as for Jabotabek, the Directorate General of Water Resources Development (DGWR) Ministry of Public Works takes the lead. Meanwhile, the PDAMs (local water supply enterprises) that carry out operations and management of water supply service are owned and supervised by the local governments.

The solution needed for the institutional problem is to create a better-coordinated system with a framework to facilitate flexible and clear roles and responsibilities of all parties involved in raw water development and to implement actions of development, regulation and law-enforcement. This need is enormously complex because it involves many issues of governance and community-building within the context of developing countries and it will take strong efforts to bring it about.

5.2.1. Implementation of Institutional Reforms

Due to fragmented or overlapping authority and programs, institutional reform will be tricky. The starting point would be the organization of a task-force to represent all parties related to Jabotabek raw water development. Table 5.1. shows the agencies/parties that should be included:

Table 5.2. Agencies/parties related to raw water development for Jabotabek and their expected roles in the planning process.

	Expected role in the planning process:	Agency or Party :	Original responsibility as (government) agency or party:
1	Lead DM/ stakeholder	The Directorate General of Water Resources Development (DGWR) Ministry of Public Work	Provides guidance in allocating surface water resources amongst users. Plays a leading role in planning, development, and management of surface water resources. For development project that needs a lot of funds beyond the yearly department's budget, cooperation & co-ordination with the National Development Planning Agency and Department of Finance is needed.
2	Influencing stakeholder	National Development Planning Agency (BAPPENAS)	Responsible for urban and rural infrastructure planning and coordination. Make overall plans for national development.
3	Influencing stakeholder	Department of Finance	Manage national budget and provide funds.
4	Core DMs/ stakeholders	River-basin Authorities : - Citarum - Ciliwung-Cisedane - Ciujung-Cidurian	O & M of water resources infrastructures in its river basin.
5	Core DM/ stakeholder	Jatiluhur Authority	O & M of Jatiluhur reservoir, which provides raw water supply for Jakarta, irrigation water for 2,685 km2 of padi fields, and generate 150 MW of electricity.
6	Perform as core DMs/ stakeholders and supporting agencies	Regional/Local governments	Under regional autonomy, regional and local governments (province & counties or cities) own and monitor PDAMs that provide water supply services, as well as providing guidelines for tariffs setting. They also control and give permit / license for groundwater abstraction on behalf of the Ministry of Mines & Energy. The Regional/Local governments also manage areas beyond forest, including recharge areas for water supply that are not forest anymore.
7	Supporting agencies	The Jakarta Water Supply Regulatory Body (JWSRB).	Perform as an independent and impartial body to regulate contracts between the regional government and the private operators in order to achieve a reasonable balance of interest between the consumer and the private water provider in Jakarta.
			Responsible for laws and regulations concerning all aspects of environmental

8	Supporting agencies	State Ministry of Environment (SMOE)	protection, including water resources. The Environmental Impact Control Board (BAPEDAL), part of State Ministry of Environment is to coordinate and control all activities for sustaining water quality in particular and for environmental quality in general.
9	Supporting agencies	The Directorate General of Human Settlements (DGHS), Ministry of Public Work	Provide guidance for the executing agency of numerous water supply and sanitation projects.
10	Supporting agencies	Department of Forestry	Manage forest areas in the river basin.
11	Raw water user	Jakarta Regional Water Supply enterprise (i.e., PAM Jaya)	O & M of urban water supply for Jakarta Metropolitan City. Some of its responsibility is contracted to Private Water Supply companies (i.e., PT. PAM Lyonnaise Jaya and PT. Aerta).
12	Raw water user	Local Water Supply Enterprises (i.e., PDAMs of Tanggerang, Bogor, and Bekasi).	O & M of urban water supply for related cities or counties beyond Jakarta Metropolitan City. (e.g., for county of Bogor is PDAM of Bogor, etc.). These agencies responsible to provide pipe water services to customers in their areas.
13	Raw water user	Private Water Supply companies : - PT. PAM Lyonnaise Jaya - PT. Thames PAM Jaya, then change to PT. Aerta.	Private water companies which have contract to provide pipe water services for parts of Jakarta Metropolitan City.
14	Advisory group	Advisory group including: - Perpamsi (Association of PDAMs of Indonesia) - Universities - Community leaders	Experience or expert in the field related to raw water development. Their knowledge and influences on public opinion are useful to management, could help to do public education and to gain public approval of decisions being made.
15	Participants	NGOs such as: - WALHI (Indonesian Forum for Environment) - YKLI (Indonesian Consumers Organization) - FORKAMI (Indonesia Drinking Water Communication Forum)	Non Governmental Agencies that are related to environmental and community/ social concerns. They represent public concerns about the Government's policy, especially on environmental and social impacts or facts that happen in the field.
16	Participants	Media representatives	Their media facilities could help to do public education and to gain public approval of decision being made.

In a real planning process, most of the government agencies would be included in the management structure shown in Table 5.2, but most of the participants and advisory groups are not included. This condition makes transparency impossible and the public has no role in the decision process because the public interest is only represented by government agencies. Other interest groups, such as universities, community leaders and NGOs, can only participate using pressure through the media.

To improve transparency, the political will of the government is needed. A report of OECD (2000) said that transparency in decision-making has been a major problem of management in developing countries for decades, in spite of the fact that it is one of fundamental elements of good governance.

5.1.2. Land-use and Urban Planning

In addition to government reform for water management, land-use and urban planning is needed to improve new developments for urban and industrial areas. Water availability and sustainability depend on the land-use conditions in watersheds that support the recharge processes for surface and groundwater. Land-use and urban planning in Jabotabek has been mainly aimed at economic growth and urban, and commercial and industrial centers are sprawled across the region. Local governments seem to give little attention to maintaining water sources. Law enforcement for violations related to inappropriate land-uses and water pollution is weak and this results in lack of vegetation on the ground to support the water recharging processes and to reduce pollution in the runoff.

For example, no law enforcement has been applied to developments that build retreat houses or resorts on water recharge areas and some local governments even change previous land-use plans to give permits for that purpose. As another example, some local governments do not act when farmers grow economic crops on hilly-lands in the upstream portions of the river basin in dense populated areas of Java island. The farmers clear grass and bushes to create cropland and this reduces water infiltration, reduces river flows, adds sediments, and generates flooding.

The solution needed is to apply an integrated approach related to land-use control, including law enforcement for violation of land-use planning. The integrated approach must be coordinated with the government's economic development policies and political will of the government is needed.

In its vision for water management, the Asian Development Bank (2003) recognizes that water sustainability can be met by the active involvement of people at all levels (i.e., national and local government, civil society groups, and communities), and that managing water resources requires a strong political will.

CHAPTER 6

CONCLUSION

The study focused on the decision making process for raw water development for large cities in developing countries, where industrial sectors create major contributions to economic growth. This is a major issue for these countries because rapid growth of industrial and urban centers close to the large cities has caused excessive groundwater abstraction resulting in severe environmental and social problems. The hypothesis was that an approach is needed for coordinated raw water management that takes into account the economic, environmental and social demands, the hydrological system and the institutional systems that exist in particular areas.

Given these complex and interacting objectives, the only way to accomplish this coordination is through an integrated approach, which begins with a cause-effect model based on system thinking, followed by process of modeling to explain the complex and interacting problems. This provides a holistic view of the raw water problems and identifies the driving forces through a DPSIR causal effect display. The analysis requires a framework for the decision-making process to address hydrologic, institutional, technical, economic, environmental and social aspects, and this is provided in the research through a decision support system that enables us to apply MCDA to analyze the integrated system and to identify the best decisions. The DSS includes a simulation model, optimization approaches based on modeling of costs and criteria, alternative solutions, criteria/sub-criteria, a matrix evaluation format, the decision-making process, and decision results.

The institutional analysis begins with stakeholder identification to include the government, other support agencies, raw water users, and participant and advisory groups. Given the government monopoly on water management, ideal approaches to institutional reform must work through existing constraints.

The analysis of the case study of the Jabotabek raw water supply system showed severe environmental and social problems due to excessive groundwater abstraction. The analysis showed that large improvements can be made through application of the integrated approach, but the success of these will depend on the political will of the government

Specific technical findings showed that the DSS could help the decision-makers to (a) find the best alternative solution of a complex problem in such way that is easy to be understood, and (b) to produce a better decision result.

The institutional analysis showed three important points:

a. It is important to establish a complete system with a coordination framework of institutional arrangements that has flexible and clear defining roles and responsibilities for all parties involved in raw water development. It must support the implementation of planned actions, including regulation and law-enforcement. If immediate institutional arrangements are needed, a task-force that represents all parties above can be created and used as temporary replacement for legal institutions. It must have clear definition of roles, responsibilities, coordination, and authorities.

b. A transparent decision-making process is needed to gain public approval and support for the development. It should include community leaders, scientific institutions/experts, and news-media in the decision process.

c. An integrated approach of all elements related to the land-use function is needed. The integrated approach may reach back to the government's policies of economic development that relates to land-use/urban planning or changing the land-use function for economic purpose. Regulations on land-use planning, groundwater abstraction and water pollution control should be applied strictly and aimed to maintain water sources in order to support raw water sustainability.

Without the government's political will to apply reforms, the problems cannot be solved because success from technical approaches will be undermined by the failure of the institutional arrangements.

Recommendation:

In order to support a decision-making process that produces a better decision result, further study and research are recommended in the following areas.

- Modeling of impacts of economic development (i.e., government policies, land-use change, and urbanization) to the local/regional hydrologic cycle is needed to help decision-makers understand the complex problems of raw water development to improve the decision result.

- Study of how to increase public participation in the decision process in developing countries is needed, because the institutional aspects and management styles of those countries are different with those in western countries.

Tortajada (2010) said that it is necessary to draw lessons by analyzing the outcomes of cases around the world which can be considered as examples of good or bad governance on water. This will enable us to understand why and how some cities have made remarkable progress in water development within limited time frames and others have not. This study provided insight into raw water issues in developing countries and should add to the data base of the case studies needed.

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APPENDICES

A. Appendix A: SURFACE RAW WATER

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Appendix A: SURFACE RAW WATER

Table A.1. Potential of raw water surface for Jabotabek urban water supply

Surface Water Availability (m3/s):

Location of raw water source:	Unregulated river		Regulated river		Max potential basin
	with *) agriculture	without agriculture	with agriculture	without agriculture	with agriculture
Ciujung river at Pamerajan :	9	13			
- include Karian			24	31	
- and Pasirkopo			31		
- and Bojongmanik			33		33
Cidurian river at Rancasumur :	3	3			
- includes Tanjung			10	12	
Cilawang river			4	4	14
Cisedane river :					
+ Present condition:					
- upstream (Bogor)	1.5				
- downstream (Serpong) **)	5				
+ Future plan:					
- upstream :					
- includes Salak canal			2		
- and Genteng			8		
- downstream **)			4		14
Ciliwung river :					
- upstream (Bogor)	1				
- downstream (Depok) **)	2				3
Bekasi river at Narogong :					
Citarum river system:					
+ Present condition:			50		
+ Future plan:					
- including operational mgnt			90		
- and Cipunegara reservoir			95		95
Less attractive option :					
- Pasiranji			11		11
- Nameng				5	5
Total Potential	21.5				175

Note :

*) : future agricultural situation

**) : water avaibility is not good in quality and depends on return flow

(source : DGWRD)

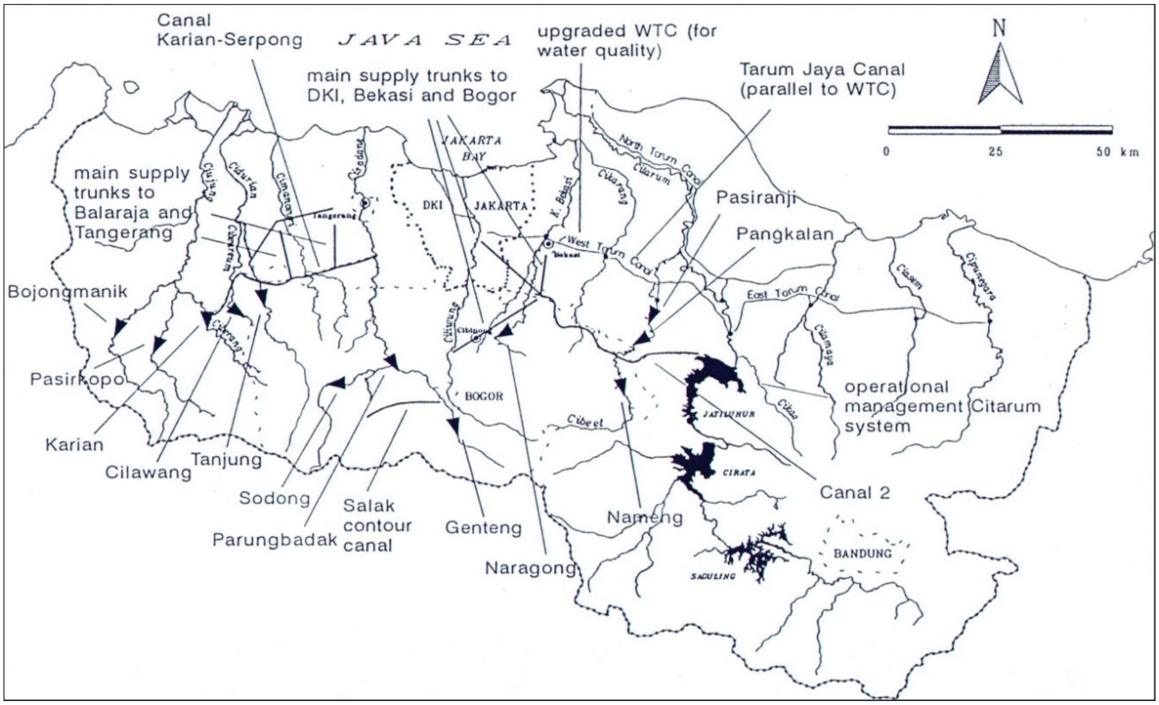


Figure A.1. Location of available raw water supply sources for Jabotabek (source : DGWRD)

Table A.2. Investment cost to built Reservoirs for Jabotabek urban water supply

Location :	People to be relocated	Capacity	Land cost	Const.cost	Total cost
	number	(m3/s)	billion Rp.	billion Rp.	billion Rp.
Bojongmanik	1000	2.0	147	228	375
Pasirkopo	2500	7.0	277	275	552
Karian	8700	15.0	791	671	1,462
Cilawang	3700	4.0	334	281	615
Tanjung	14700	7.0	1,035	1,108	2,143
Genteng *)	1800	6.5	252	2,651	2,903
Narogong	6800	6.0	609	268	877
Raising Cirata reservoir	13500	15.0	650	1,917	2,567

Note : *) : Construction cost is including relocation of railway track.
(source : DGWRD with adjustment)

Table A.3. Investment cost to build Western conveyance system for Jabotabek

Location or Project :	Length (km)	Capacity rn3/s	Land cost billion Rp.	Const.cost billion Rp.	Total cost billion Rp.
Cidurian canal extension:					
- high capacity	30	21.0	182	162	343
- low capacity	30	7.0	182	148	329
Karian - Parungpanjang:					
- high capacity	30	26.0	95	248	343
- low capacity	30	12.0	95	209	304
Karian - DKI Jkt connection:					
- high capacity		8.5	878	633	1,512
- extension to Serpong		6.0	845	410	1,256
- replacement Serpong		3.0	845	194	1,040
Main trunks:					
- to Balaraja	15				
-* first pipe		4.5	20	252	273
-* next pipe		4.5	10	252	263
- to Tangerang	17				
-* first pipe		4.5	17	223	240
-* next pipe		4.5	8	223	231

Note : Costs as in August 2009, US$ 1 = Rp. 9,000
(source : DGWRD with adjustment)

Table A.4. Investment cost to build Southern conveyance system for Jabotabek

Location or Project :	Length (km)	Capacity rn3/s	Land cost billion Rp.	Const.cost billion Rp.	Total cost billion Rp.
Salak contour canal	16.5	2.0	64	542	607
Main trunk from Narogong (plus pumping ststion) :					
- to Bogor North	15	3.3	24	250	275
- to Bogor South	22	2.7	41	700	741
Main trunk from Genteng reservoir	5	8.0	18	149	167

(source : DGWRD with adjustment)

Table A.5. Investment cost to build Eastern conveyance system for Jabotabek

Location or Project :	Length	Capacity	Land cost	Const.cost	Total cost
	(km)	rn3/s	billion Rp.	billion Rp.	billion Rp.
WTC Adaptatian			15	48	63
Extension of WTC :					
- 11.2 m3/s	50	11.2	191	59	250
Canal-1 :	50				
- Open Canal :					
- high capacity		44.9	724	326	1,050
- low capacity		15.1	615	255	870
- Pipe :					
- high capacity		44.9	410	7,578	7,988
- low capacity		15.1	164	3,123	3,287
Canal-2 :	52.5				
- IncIuding Ps.Gambung intake					338
- Open Canal :					
- 44.9 m3/s		44.9	269	941	1,211
- 38.4 m3/s		38.4	236	900	1,136
- 14.2 m3/s		14.2	106	743	849
- Pipe :					
- 44.9 m3/s		44.9	95	8,135	8,229
- 15.1 m3/s		15.1	38	3,214	3,252
Main trunks Canal-1:					
- Bekasi - Cakung :	9	6.0		161	
- first pipe			22		183
- next pipe			11		172
- Bekasi - DKI South	30	6.0	318	589	907
- Bekasl - Lelakbulus :	37	6.0		675	
- first pipe			392		1,068
- next pipe	25		196		872
- Bekasi - Bogor North	45	6.0	61	468	529
- Bekasi - Bogor South :		6.0		1,229	
- first pipe			110		1,340
- next pipe			55		1,285
Main trunks Canal-2:					
- Babakan - Cakung :	15	4.5		223	
- first pipe			23		246
- next pipe			12		234
- Babakan - DKI South	16	4.5	113	265	378
- Babakan - Lebakbulus :	25	6.0		399	
- first pipe			176		575
- next pipe			88		487
- Babakan - Bekasi :	19	4.5		282	
- first pipe			30		312
- next pipe			15		297
- Babakan - Bogor North	15	6.0	25	277	302
- Babakan - Bogor South :	25	6.0		868	
- first pipe			50		918
- next pipe			25		893

(source : DGWRD with adjustment)

Appendix B: RESULTS OF THE MODELS

B.1. Results of Supply_sim model

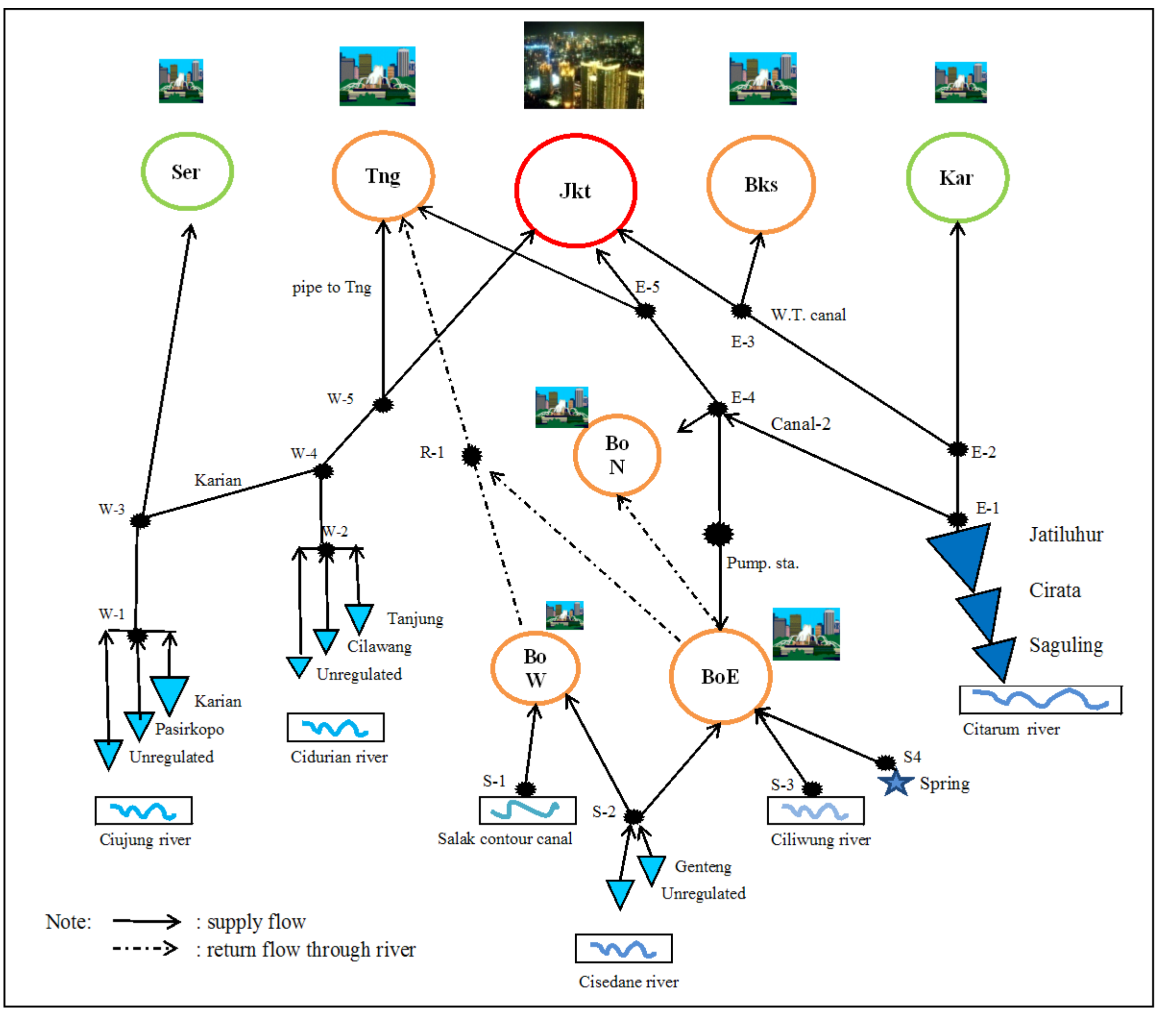


Figure B.1.1. Layout of network for Jabotabek raw water supply development

Table B.1.1. Raw water supply allocation for alternative A-1

Supply_sim Model

Developed by: Edy A. Soentoro

Raw Water Supply Allocation

Urban center	Serang Ser	Tanggerang Tng	Jakarta Jkt	Bekasi Bks	Karawang Kar	Bogor North BoN	Bogor East BoE	Bogor West BoW	Total
Water demand	17.3	22.2	42.1	16.2	18.1	5.4	10.8	3.3	135.40
Surface water supply	14.61	18.74	35.36	13.61	15.20	4.54	9.07	2.77	113.90
Groundwater supply	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total water supply	14.61	18.74	35.36	13.61	15.20	4.54	9.07	2.77	113.90
Supply /demand (%)	84.4	84.4	84.0	84.0	84.0	84.0	84.0	84.0	84.1

Source of raw water supply :	Surface raw water				Groundwater	
(from actual release)	West-1	West-2	East-1	South	Retr. flow	GW	Total
(in m3/s)	24.00	3.00	75.00	5.90	6.00	0.00	113.90

Fraction of flow	w3-sr/w1-3	w5-tng/w4-5	e1-2/e1	e2-3/e12	e3-jkt/e2-3	e4-5/e1-4	e4-bo-n/e4-5	e5-jkt/e4-5	s2-boe/s2
Fract. estimation	0.609	0.020	0.389	0.479	0.026	0.815	0.055	0.612	0.485

River	Reservoir	Max. Release	Act. Release	Canal	Flows	Canal	Flows	Grounwater pumping:	
Ciujung:	Karian	15	15	West :		East :		max /location	
	Pasirkopo	7	0	W1-W3	24.00	E1-E2	29.17	(m3/s):	0
	Unregulated	9	9	W3-Ser	14.61	E2-Kar	15.20	(mgd):	0.00
Cidurian:	Tanjung	7	0	W3-W4	9.39	E2-E3	13.97	City/Area:	
	Cilawang	4	0	W2-W4	3.00	E3-Bks	13.61	Bo-N :	
	Unregulated	3	3	W4-W5	12.39	E3-Jkt	0.36	# of location:	1
Citarum:	Jatiluhur	50	50	W5-Tng	0.25	E1-E4	45.83	max (m3/s):	0
	* flow prediction	10	10	W5-Jkt	12.15	E4-E5	37.35	actual (m3/s):	0
	* drought mngmt.	10	10			E4-BoN	2.54	Bo-E :	
	* on demand irrigation	5	5	South :		E4-BoSE	5.94	# of location:	2
	* raised Cirata dam	15	0	S1-BoW	2	E5-Jkt	22.86	max (m3/s):	0
Cisedane:	Genteng	6.5	0	S2-BoW	0.77	E5-Tng	14.49	actual (m3/s):	0
	Unregulated	1.5	1.5	S2-BoE	0.73			Bo-W :	
	Salak canal	2	2	S3-BoE	2.00	Return flow:		# of location:	1
	downst.flow-W	3	3	S4-BoE	0.40	BoE-BoN	2.00	max (m3/s):	0
	downst.flow-E	1	1			BoE-R1	1.00	actual (m3/s):	0
Ciliwung :	upstream flow	2	2			BoW-R1	3.00		
	spring	0.4	0.4			R1-Tng	4.00		
	downst.flow	2	2						

Instruction : [green box] : decide water demands, actual release from reservoirs and groundwater wells
actual release from a reservoir will mean that the reservoir should be built or is ready there
[blue box] : enter the fraction estimation to find the best result

Note : Jatiluhur-Cirata-Saguling (E1) are the only existing reservoirs in the network right now, the others are need to be built.
Present West Tarum canal has max. capacity 24 m3/s, other conveyance systems are need to be built or through rivers

Table B.1.2. Raw water supply allocation for alternative A-2

Supply_sim Model

Developed by: Edy A. Soentoro

Raw Water Supply Allocation

Urban center	Serang Ser	Tanggerang Tng	Jakarta Jkt	Bekasi Bks	Karawang Kar	Bogor North BoN	Bogor East BoE	Bogor West BoW	Total
Water demand	17.3	22.2	42.1	16.2	18.1	5.4	10.8	3.3	135.40
Surface water supply	13.84	22.20	42.10	16.20	14.84	4.40	8.67	2.64	124.90
Groundwater supply	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total water supply	13.84	22.20	42.10	16.20	14.84	4.40	8.67	2.64	124.90
Supply /demand (%)	*80.0*	*100.0*	*100.0*	*100.0*	*82.0*	*81.6*	*80.3*	*80.0*	*92.2*

Source of raw water supply :		Surface raw water					Groundwater	
(from actual release)		West-1	West-2	East-1	South	Retr. flow	GW	**Total**
	(in m3/s)	31.00	7.00	75.00	5.90	6.00	0.00	124.90

Fraction of flow	w3-sr/w1-3	w5-tng/w4-5	e1-2/e1	e2-3/e12	e3-jkt/e2-3	e4-5/e1-4	e4-bo-n/e4-5	e5-jkt/e4-5	s2-boe/s2
Fract. estimation	0.446	0.000	0.414	0.522	0.000	0.822	0.055	0.496	0.573

River	Reservoir	Max. Release	Act. Release	Canal	Flows	Canal	Flows	Grounwater pumping:	
Ciujung:	Karian	15	15	**West :**		**East :**		max /location	
	Pasirkopo	7	7	W1-W3	31.00	E1-E2	31.04	(m3/s):	0
	Unregulated	9	9	W3-Ser	13.84	E2-Kar	14.84	(mgd):	0.00
Cidurian:	Tanjung	7	0	W3-W4	17.16	E2-E3	16.20	**City/Area:**	
	Cilawang	4	4	W2-W4	7.00	E3-Bks	16.20	**Bo-N :**	
	Unregulated	3	3	W4-W5	24.16	E3-Jkt	0.00	# of location:	1
Citarum:	Jatiluhur	50	50	W5-Tng	0.00	E1-E4	43.96	max (m3/s):	0
	* flow prediction	10	10	W5-Jkt	24.16	E4-E5	36.14	actual (m3/s):	0
	* drought mngmt.	10	10			E4-BoN	2.40	**Bo-E :**	
	* on demand irrigation	5	5	**South :**		E4-BoSE	5.41	# of location:	2
	* raised Cirata dam	15	0	S1-BoW	2	E5-Jkt	17.94	max (m3/s):	0
Cisedane:	Genteng	6.5	0	S2-BoW	0.64	E5-Tng	18.20	actual (m3/s):	0
	Unregulated	1.5	1.5	S2-BoE	0.86			**Bo-W :**	
	Salak canal	2	2	S3-BoE	2.00	**Return flow:**		# of location:	1
	downst.flow-W	3	3	S4-BoE	0.40	BoE-BoN	2.00	max (m3/s):	0
	downst.flow-E	1	1			BoE-R1	1.00	actual (m3/s):	0
Ciliwung :	upstream flow	2	2			BoW-R1	3.00		
	spring	0.4	0.4			R1-Tng	4.00		
	downst.flow	2	2						

Instruction : [green box] : decide water demands, actual release from reservoirs and groundwater wells
actual release from a reservoir will mean that the reservoir should be built or is ready there
[blue box] : enter the fraction estimation to find the best result

Note : Jatiluhur-Cirata-Saguling (E1) are the only existing reservoirs in the network right now, the others are need to be built.
Present West Tarum canal has max. capacity 24 m3/s, other conveyance systems are need to be built or through rivers

Table B.1.3. Raw water supply allocation for alternative A-3

Supply_sim Model

Developed by: Edy A. Soentoro

Raw Water Supply Allocation

Urban center	Serang Ser	Tanggerang Tng	Jakarta Jkt	Bekasi Bks	Karawang Kar	Bogor North BoN	Bogor East BoE	Bogor West BoW	Total
Water demand	17.3	22.2	42.1	16.2	18.1	5.4	10.8	3.3	135.40
Surface water supply	15.05	22.20	42.10	16.20	16.02	3.78	7.56	2.00	124.90
Groundwater supply	0.00	0.00	0.00	0.00	0.00	1.00	2.00	1.00	4.00
Total water supply	15.05	22.20	42.10	16.20	16.02	4.78	9.56	3.00	128.90
Supply /demand (%)	*87.0*	***100.0***	***100.0***	***100.0***	***88.5***	***88.5***	***88.5***	***90.9***	***95.2***

Source of raw water supply :		Surface raw water					Groundwater	
(from actual release)		West-1	West-2	East-1	South	Retr. flow	GW	**Total**
	(in m3/s)	31.00	7.00	75.00	5.90	6.00	4.00	128.90

Fraction of flow	w3-sr/w1-3	w5-tng/w4-5	e1-2/e1	e2-3/e12	e3-jkt/e2-3	e4-5/e1-4	e4-bo-n/e4-5	e5-jkt/e4-5	s2-boe/s2
Fract. estimation	0.486	0.000	0.430	0.503	0.000	0.873	0.042	0.513	1.000

River	Reservoir	Max. Release	Act. Release	Canal	Flows	Canal	Flows	Grounwater pumping:	
Ciujung:	Karian	15	15	**West :**		**East :**		max /location	
	Pasirkopo	7	7	W1-W3	31.00	E1-E2	32.22	(m3/s):	1
	Unregulated	9	9	W3-Ser	15.05	E2-Kar	16.02	(mgd):	22.83
Cidurian:	Tanjung	7	0	W3-W4	15.95	E2-E3	16.20	**City/Area:**	
	Cilawang	4	4	W2-W4	7.00	E3-Bks	16.20	**Bo-N :**	
	Unregulated	3	3	W4-W5	22.95	E3-Jkt	0.00	# of location:	1
Citarum:	Jatiluhur	50	50	W5-Tng	0.00	E1-E4	42.78	max (m3/s):	1
	* flow prediction	10	10	W5-Jkt	22.95	E4-E5	37.35	actual (m3/s):	1
	* drought mngmt.	10	10			E4-BoN	1.78	**Bo-E :**	
	* on demand irrigation	5	5	**South :**		E4-BoSE	3.66	# of location:	2
	* raised Cirata dam	15	0	S1-BoW	2	E5-Jkt	19.15	max (m3/s):	2
Cisedane:	Genteng	6.5	0	S2-BoW	0.00	E5-Tng	18.20	actual (m3/s):	2
	Unregulated	1.5	1.5	S2-BoE	1.50			**Bo-W :**	
	Salak canal	2	2	S3-BoE	2.00	**Return flow:**		# of location:	1
	downst.flow-W	3	3	S4-BoE	0.40	BoE-BoN	2.00	max (m3/s):	1
	downst.flow-E	1	1			BoE-R1	1.00	actual (m3/s):	1
Ciliwung :	upstream flow	2	2			BoW-R1	3.00		
	spring	0.4	0.4			R1-Tng	4.00		
	downst.flow	2	2						

Instruction : [green box] : decide water demands, actual release from reservoirs and groundwater wells
actual release from a reservoir will mean that the reservoir should be built or is ready there
[blue box] : enter the fraction estimation to find the best result

Note : Jatiluhur-Cirata-Saguling (E1) are the only existing reservoirs in the network right now, the others are need to be built.
Present West Tarum canal has max. capacity 24 m3/s, other conveyance systems are need to be built or through rivers

Table B.1.4. Raw water supply allocation for alternative A-4

Supply_sim Model

Developed by: Edy A. Soentoro

Raw Water Supply Allocation

Urban center	Serang Ser	Tanggerang Tng	Jakarta Jkt	Bekasi Bks	Karawang Kar	Bogor North BoN	Bogor East BoE	Bogor West BoW	Total
Water demand	17.3	22.2	42.1	16.2	18.1	5.4	10.8	3.3	135.40
Surface water supply	17.30	22.20	42.10	16.20	18.10	4.40	8.80	2.30	131.40
Groundwater supply	0.00	0.00	0.00	0.00	0.00	1.00	2.00	1.00	4.00
Total water supply	17.30	22.20	42.10	16.20	18.10	5.40	10.80	3.30	135.40
Supply /demand (%)	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*

Source of raw water supply :	Surface raw water					Groundwater	
(from actual release)	West-1	West-2	East-1	South	Retr. flow	GW	Total
(in m3/s)	31.00	7.00	75.00	12.40	6.00	4.00	135.40

Fraction of flow	w3-sr/w1-3	w5-tng/w4-5	e1-2/e1	e2-3/e12	e3-jkt/e2-3	e4-5/e1-4	e4-bo-n/e4-5	e5-jkt/e4-5	s2-boe/s2
Fract. estimation	0.558	0.151	0.457	0.472	0.000	0.973	0.059	0.620	0.963

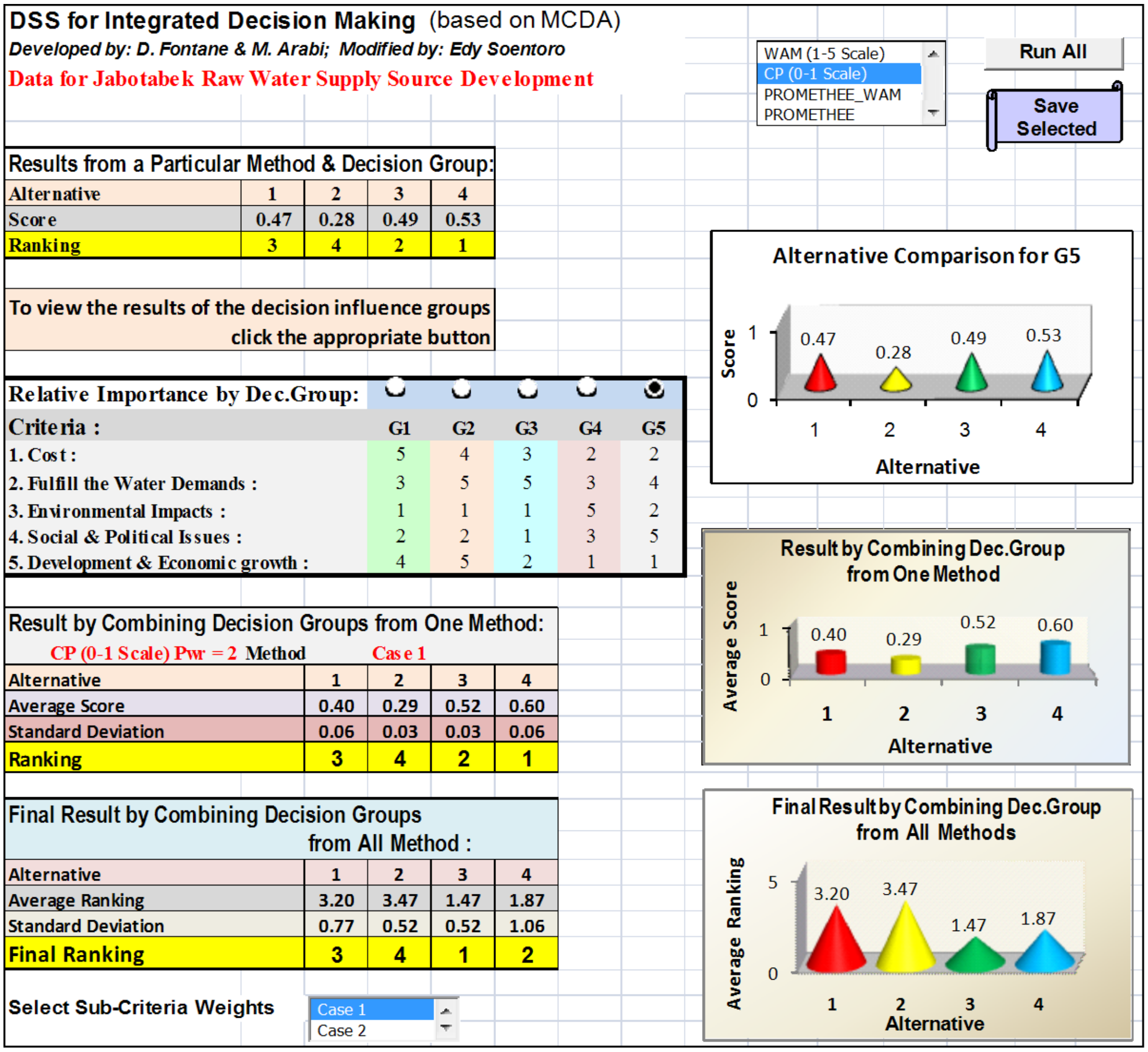
River	Reservoir	Max. Release	Act. Release	Canal	Flows	Canal	Flows	Grounwater pumping:	
Ciujung:	Karian	15	15	West :		East :		max /location	
	Pasirkopo	7	7	W1-W3	31.00	E1-E2	34.30	(m3/s):	1
	Unregulated	9	9	W3-Ser	17.30	E2-Kar	18.10	(mgd):	22.83
Cidurian:	Tanjung	7	0	W3-W4	13.70	E2-E3	16.20	City/Area:	
	Cilawang	4	4	W2-W4	7.00	E3-Bks	16.20	Bo-N :	
	Unregulated	3	3	W4-W5	20.70	E3-Jkt	0.00	# of location:	1
Citarum:	Jatiluhur	50	50	W5-Tng	3.13	E1-E4	40.70	max (m3/s):	1
	* flow prediction	10	10	W5-Jkt	17.57	E4-E5	39.60	actual (m3/s):	1
	* drought mngmt.	10	10			E4-BoN	2.40	Bo-E :	
	* on demand irrigation	5	5	South :		E4-BoSE	-1.30	# of location:	2
	* raised Cirata dam	15	0	S1-BoW	2	E5-Jkt	24.53	max (m3/s):	2
Cisedane:	Genteng	6.5	6.5	S2-BoW	0.30	E5-Tng	15.07	actual (m3/s):	2
	Unregulated	1.5	1.5	S2-BoE	7.70			Bo-W :	
	Salak canal	2	2	S3-BoE	2.00	Return flow:		# of location:	1
	downst.flow-W	3	3	S4-BoE	0.40	BoE-BoN	2.00	max (m3/s):	1
	downst.flow-E	1	1			BoE-R1	1.00	actual (m3/s):	1
Ciliwung :	upstream flow	2	2			BoW-R1	3.00		
	spring	0.4	0.4			R1-Tng	4.00		
	downst.flow	2	2						

Instruction : [green box] : decide water demands, actual release from reservoirs and groundwater wells
actual release from a reservoir will mean that the reservoir should be built or is ready there
[blue box] : enter the fraction estimation to find the best result

Note : Jatiluhur-Cirata-Saguling (E1) are the only existing reservoirs in the network right now, the others are need to be built.
Present West Tarum canal has max. capacity 24 m3/s, other conveyance systems are need to be built or through rivers

B.2. Results of DSS of IDM Model

B.2.1. Preliminary Ranking Result



DSS for Integrated Decision Making (based on MCDA)

Developed by: D. Fontane & M. Arabi; Modified by: Edy Soentoro

Data for Jabotabek Raw Water Supply Source Development

WAM (1-5 Scale)
CP (0-1 Scale)
PROMETHEE_WAM
PROMETHEE

Run All

Save Selected

Results from a Particular Method & Decision Group:

Alternative	1	2	3	4
Score	0.47	0.28	0.49	0.53
Ranking	3	4	2	1

To view the results of the decision influence groups click the appropriate button

Relative Importance by Dec.Group:

Criteria :	G1	G2	G3	G4	G5
1. Cost :	5	4	3	2	2
2. Fulfill the Water Demands :	3	5	5	3	4
3. Environmental Impacts :	1	1	1	5	2
4. Social & Political Issues :	2	2	1	3	5
5. Development & Economic growth :	4	5	2	1	1

Result by Combining Decision Groups from One Method:

CP (0-1 Scale) Pwr = 2 Method Case 1

Alternative	1	2	3	4
Average Score	0.40	0.29	0.52	0.60
Standard Deviation	0.06	0.03	0.03	0.06
Ranking	3	4	2	1

Final Result by Combining Decision Groups from All Method :

Alternative	1	2	3	4
Average Ranking	3.20	3.47	1.47	1.87
Standard Deviation	0.77	0.52	0.52	1.06
Final Ranking	3	4	1	2

Select Sub-Criteria Weights
Case 1
Case 2

Figure B.2.1.1. Result of DSS of IDM based on CP method with p=2

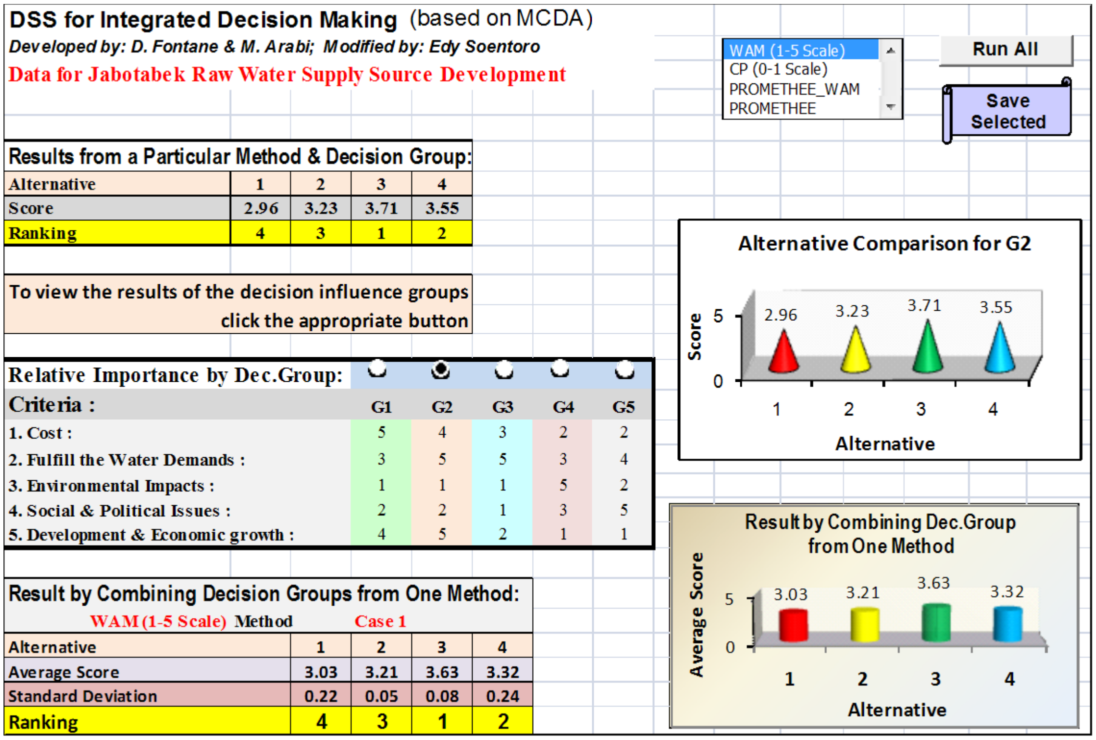


Figure B.2.1.2. Result of DSS of IDM based on WAM method

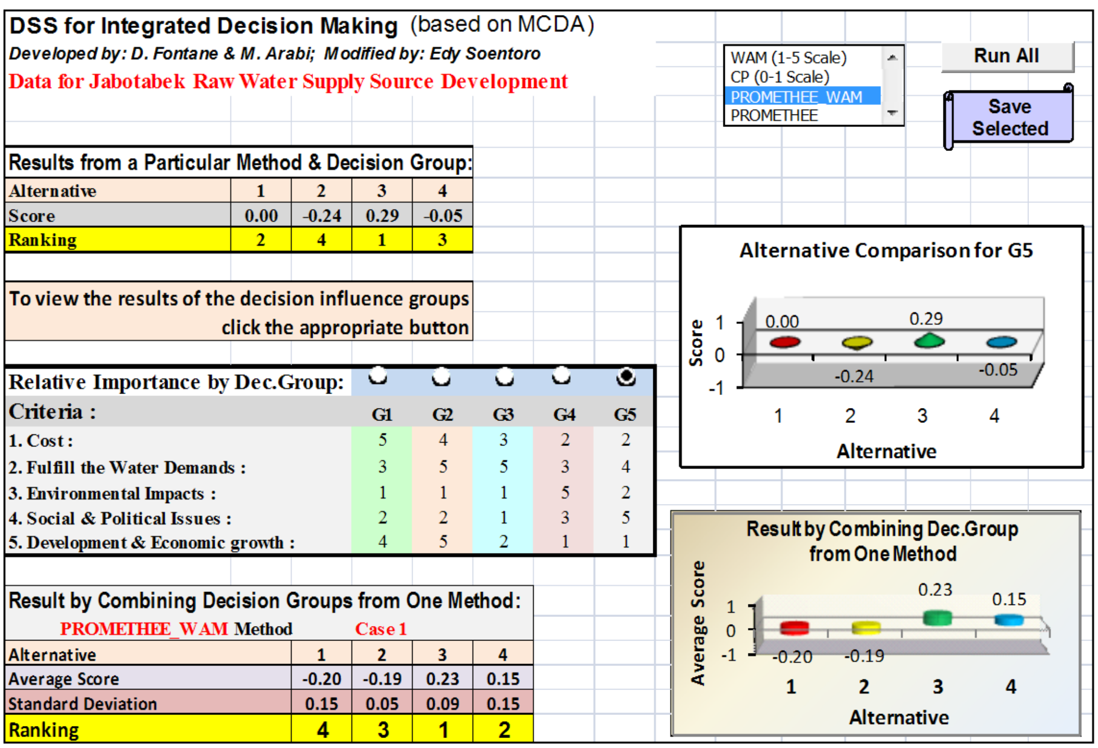


Figure B.2.1.3. Result of DSS of based on Promethee_WAM method

B.2.2. Final Ranking

DSS for Integrated Decision Making (based on MCDA)

Developed by: D. Fontane & M. Arabi; Modified by: Edy Soentoro

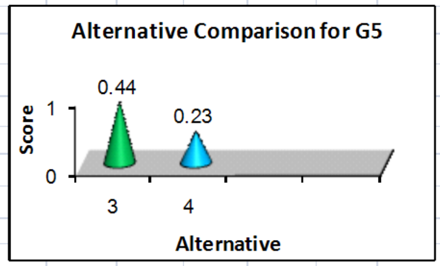
Data for Jabotabek Raw Water Supply Source Development

WAM (1-5 Scale)
CP (0-1 Scale)
PROMETHEE_WAM
PROMETHEE

Run All

Save Selected

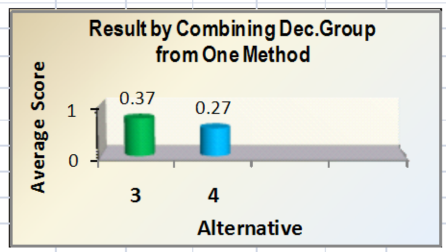
Results from a Particular Method & Decision Group:				
Alternative	3	4		
Score	0.44	0.23		
Ranking	1	2		



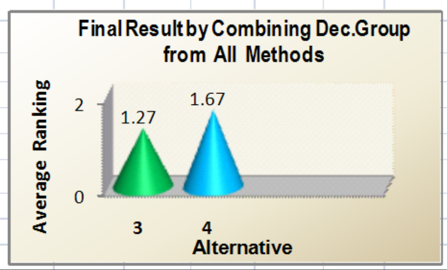
To view the results of the decision influence groups click the appropriate button

Relative Importance by Dec.Group:					
Criteria :	G1	G2	G3	G4	G5
1. Cost :	5	4	3	2	2
2. Fulfill the Water Demands :	3	5	5	3	4
3. Environmental Impacts :	1	1	1	5	2
4. Social & Political Issues :	2	2	1	3	5
5. Development & Economic growth :	4	5	2	1	1

Result by Combining Decision Groups from One Method:				
CP (0-1 Scale) Pwr = 2 Method		Case 1		
Alternative	3	4		
Average Score	0.37	0.27		
Standard Deviation	0.06	0.08		
Ranking	1	2		



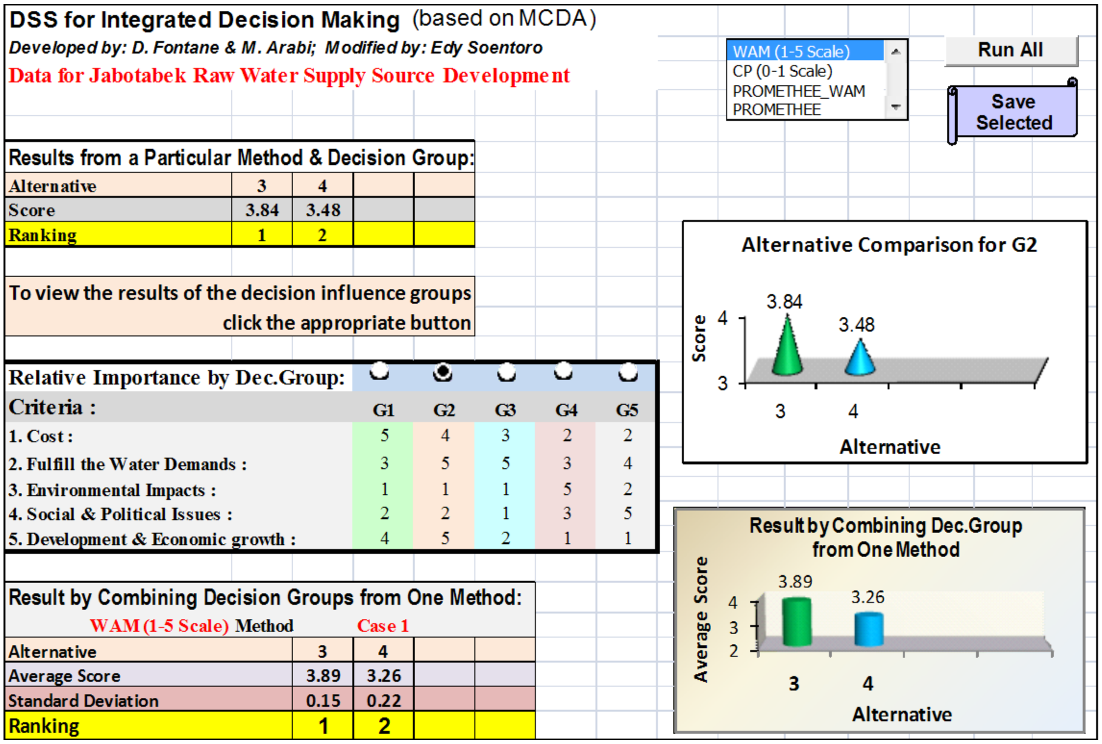
Final Result by Combining Decision Groups from All Method :				
Alternative	3	4		
Average Ranking	1.27	1.67		
Standard Deviation	0.46	0.49		
Final Ranking	3	4		



Select Sub-Criteria Weights

Case 1
Case 2

Figure B.2.2.1. Result of DSS of IDM based on CP method with p=2



DSS for Integrated Decision Making (based on MCDA)

Developed by: D. Fontane & M. Arabi; Modified by: Edy Soentoro

Data for Jabotabek Raw Water Supply Source Development

Results from a Particular Method & Decision Group:

Alternative	3	4		
Score	3.84	3.48		
Ranking	1	2		

To view the results of the decision influence groups click the appropriate button

Relative Importance by Dec.Group:

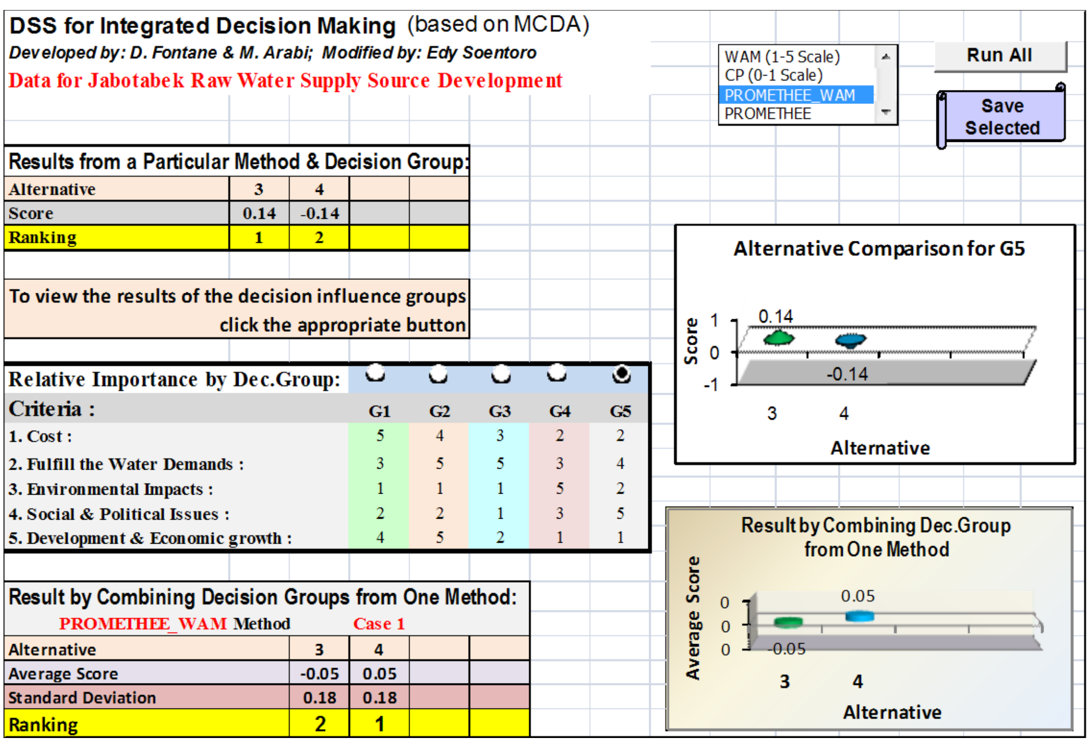
Criteria :	G1	G2	G3	G4	G5
1. Cost :	5	4	3	2	2
2. Fulfill the Water Demands :	3	5	5	3	4
3. Environmental Impacts :	1	1	1	5	2
4. Social & Political Issues :	2	2	1	3	5
5. Development & Economic growth :	4	5	2	1	1

Result by Combining Decision Groups from One Method:

WAM (1-5 Scale) Method — Case 1

Alternative	3	4		
Average Score	3.89	3.26		
Standard Deviation	0.15	0.22		
Ranking	1	2		

Figure B.2.2.2. Result of DSS of IDM based on WAM method



DSS for Integrated Decision Making (based on MCDA)

Developed by: D. Fontane & M. Arabi; Modified by: Edy Soentoro

Data for Jabotabek Raw Water Supply Source Development

Results from a Particular Method & Decision Group:

Alternative	3	4		
Score	0.14	-0.14		
Ranking	1	2		

To view the results of the decision influence groups click the appropriate button

Relative Importance by Dec.Group:

Criteria :	G1	G2	G3	G4	G5
1. Cost :	5	4	3	2	2
2. Fulfill the Water Demands :	3	5	5	3	4
3. Environmental Impacts :	1	1	1	5	2
4. Social & Political Issues :	2	2	1	3	5
5. Development & Economic growth :	4	5	2	1	1

Result by Combining Decision Groups from One Method:

PROMETHEE_WAM Method — Case 1

Alternative	3	4		
Average Score	-0.05	0.05		
Standard Deviation	0.18	0.18		
Ranking	2	1		

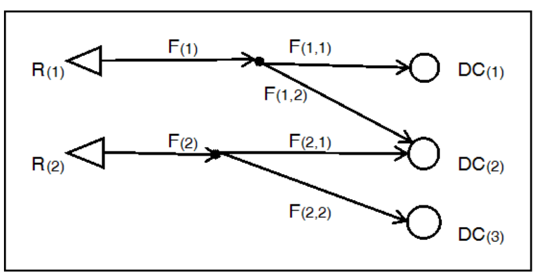
Figure B.2.2.3. Result of DSS of IDM based on Promethee_WAM method

Appendix C: SUPPLY_SIM MODEL

Supply_sim model is a model for calculating water supply allocation for each demand cluster in the water supply network. Developed by the author in a spreadsheet, the model uses simulation and optimization methods to help calculation procedure in the DSS model. The model is used to calculate water supply allocation to each demand cluster, how many percentage of water supply per water demand can be fulfilled, and where the raw water supply comes from. Information about water supply allocation for each demand cluster is very important data for the next planning procedure in the DSS. Calculation for the planned capacity and construction cost of reservoir, conveyance system and land acquisition cost depends on information above. Assessment for some other alternative's performance in the DSS also depends on calculating water supply allocation for each demand cluster.

C.1. Basic Concept of Supply_sim model

The Supply_sim model applies network flow simulation in the spreadsheet, then it optimizes the percentage of supply/demand for each demand clusters by using "solver" tool of the spreadsheet. Based on network flow below, applying simulation procedure on the network flow produce:



1. Flow pass through the node:

   $F(i,j) = FR(j) * F(i)$

   $FR(j) \leq 1$

2. Network flow simulation:

   a. $S(1) = F(1,1)$

      $S(2) = F(1,2) + F(2,1)$

      $S(3) = F(2,2)$

   b. $F(1) = F(1,1) + F(1,2)$

      $F(2) = F(2,1) + F(2,2)$

   c. $\sum_1^n S(i) = \sum_1^n F(i)$

in which:

R : reservoir
DC : demand cluster
F : flow discharge of water supply
S : actual supply discharge to DC
D : water demand of DC
FR(j) : fraction flow of main flow F(i) that go to F(i,2), equal to F(i,2) / F(i)

The optimization objective is to minimize the different percentage of supply/demand among demand clusters:

Minimize : TLDELTA = $\sum_1^n$ DELTA (i)

Subject to :
1. DELTA(i) = Absolute {PR(i) – PR(i+1)}
2. PR(i) $\leq$ 100
3. FR(i) $\leq$ 1
4. Network flow simulation :
    a. S(1) = F(1,1)
       S(2) = F(1,2) + F(2,1)
       S(3) = F(2,2)
    b. F(1) = F(1,1) + F(1,2)
       F(2) = F(2,1) + F(2,2)
    c. $\sum_1^n$ S (i) = $\sum_1^n$ F (i)

in which:

TDELTA : total difference percentage of supply/demand of all DCs
DELTA : difference percentage of supply/demand of adjacent DCs
PR(i) : percentage of supply/demand = 100 * S(i) / D(i)

The Solver tool in the spreadsheet finds solution of the optimization through calculus based search approach (e.g., Gradient search). It uses combination of direction search and step size to get an efficient search process. Gradient search works well to find solution (i.e., maxima or minima, local maxima or local minima) for unconstrained optimization problem. Meanwhile for constrained optimization problem, the problem is converted into unconstrained problem through the use of Lagrangian multiplier (i.e., λ) as a penalty term to force a feasible solution. Example of the use Lagrangian multiplier is presented as below:

Minimize $L = f(x)$
Subject to : $g_i(x) = b_i$

From equation above, let we transform the optimization equation above with Lagrangian multiplier equation as:

Minimize : $L(x, \lambda) = f(x) + \sum_{i=1}^{m} \lambda_i [g_i(x) - b_i]$

Optimal solution (i.e., minima point) can be found where all the derivatives of function above are equal to zero: $\frac{d\ L(x,\lambda)}{dx} = 0$ and $\frac{d\ L(x,\lambda)}{d\lambda} = 0$, in which all constraints must be satisfied.

C.2. Calculation Procedure

Calculation procedure in the Supply_sim is as follow:

1. Decide water demand D(i) for each demand clusters. Water demand for each cluster is determined based on demand estimation for year 2025, with assumption of continues economic growth is 7%/year. Since the present economic growth may less than 7%, the actual water demand may be less than those in the data. The Supply_sim model is completed by " % adjustment" to make adjustment of water demands by any percentage, if the economic growth is not equal to 7%/year.
2. Decide actual water supply release F(i) from each storage/ reservoir in the network flow, including from spring flows and river's intake structure. Actual release from a reservoir will mean that the reservoir should be built or it was ready there. If a particular reservoir is not built or not to be intended to give water supply, so the actual water release is zero.
3. In the solver constrain, decide what we want, either almost the same percentage of supply per demand for each cluster, or any percentage number for particular clusters. Then, make adjustment in solver constrains.
4. Enter the fraction estimation FR(i) of supply flow per total flow at every branch of conveyance system in the network flow.
5. Using Solver, optimize the water supply allocation for each demand cluster. Based on network flow layout of raw water supply for Jabotabek with many demand clusters, application of Supply_sim model will generate local optima. So, the fraction estimation FR(i) in the step (4) above may have to be adjusted several times to find the real optima.

C.3. Operational Management for Citarum River System

Based on JWRMS study (DGWR, 1992), there is option to raise supply release from Jatiluhur reservoir through operational management of reservoirs in Citarum river. The operational management refers to the improved operation of existing infrastructures and facilities and a continue attention to an efficient operation. It will reduce huge investments (e.g., to build a new reservoir) and avoid problems (e.g., relocate many people due to build a new reservoir, political difficulties, social & environmental problems).

Options of the operational management for Citarum river system includes:

a. Flow prediction:
   It is to improve reservoir operation based on real-time forecasting of unregulated flows. Diversion flow available from unregulated river in the system is added to flow from the reservoir. More accurate forecasting of the unregulated flows will allow more efficient the use of flow from the reservoir, and save water from reservoir for later use in dry period.

b. Drought management:
   In anticipation of extreme drought, flows for parts of irrigation network canal may be disconnected to save water for M & I (municipal & industrial) water. It is possible

since the Jatiluhur reservoir also supplies irrigation water for large area of padi (rice) field. If any damage of padi field occurs due to the flow disconnection, then the farmers are reimbursed for their losses. This method is much cheaper than to build a new reservoir.

c. On-demand irrigation:
   Irrigation water demand varies over the time depending on the stage of plant's growth and season (e.g., dry and wet season). Rainfall input in wet season can provide supplement of water in padi field so that it reduce water supply from irrigation canal. During period of high rainfall the flows to irrigation canals may be reduced and the water can be saved in reservoir for M & I demand and for later use in dry period. Again, this method is much cheaper than to build a new reservoir.
d. Raising Cirata dam:
   There are three existing reservoirs in the Citarum river system, Jatiluhur, Cirata, and Saguling, respectively from downstream to upstream. Cirata & Saguling reservoirs are mainly used for hydropower generation. The foundation of Cirata dam has been constructed so that a future of raising the dam up to 15 m will be possible. When the dam had been built in the 1980s, the increased benefit from hydropower generation was not sufficient enough to justify a high dam. The tight water supply situation foreseen in the 21th century together with the extra hydropower benefits may guarantee a raise of the dam in the future. The benefit of raising the dam should be followed by an efficient reservoir operation of the three cascade dams in the Citarum river system.

Impact of the operational management of Citarum river system will contribute a lot in providing raw water supply as well as reducing the need to build additional reservoir to fulfill water demands for Jabotabek.

C.4. Example of the Supply_sim Result

Supply_sim model worksheet contains data of :

a. Available raw water supply source (existing and proposed reservoirs, diversion from unregulated river, return flows, and springs/head water), including their maximum releases and actual releases.
b. Urban centers (or demand cluster), estimated water demands for the year 2025, water supply and the percentage of supply per demand for each demand cluster.
c. Network flows through existing and proposed conveyance system from raw water supply source to demand clusters. The existing conveyance system is West Tarum canal (E2-E3) that carries water from Jatiluhur reservoir to Jakarta. Simulation technique is applied in the network flows so that flow discharge in any section of the conveyance may influence discharge in other sections.

Result from Supply_sim model is raw surface water supply allocation for a particular objective. Example of the result for alternative A-3 is presented in table D.1. The objective of alternative A-3 is to use groundwater from Bogor areas up to maximum available permit to add more supply of water, and fulfill demand in areas of land-subsidence (i.e., Jakarta, Tanggerang, and Bekasi).

Table C.1. Example of calculation result from Supply_sim model

Supply_sim Model
Developed by: Edy A. Soentoro

Raw Water Supply Allocation

Urban center	Serang Ser	Tanggerang Tng	Jakarta Jkt	Bekasi Bks	Karawang Kar	Bogor North BoN	Bogor East BoE	Bogor West BoW	Total
Water demand	17.3	22.2	42.1	16.2	18.1	5.4	10.8	3.3	135.40
Surface water supply	15.05	22.20	42.10	16.20	16.02	3.78	7.56	2.00	124.90
Groundwater supply	0.00	0.00	0.00	0.00	0.00	1.00	2.00	1.00	4.00
Total water supply	15.05	22.20	42.10	16.20	16.02	4.78	9.56	3.00	128.90
Supply /demand (%)	*87.0*	*100.0*	*100.0*	*100.0*	*88.5*	*88.5*	*88.5*	*90.9*	*95.2*

Source of raw water supply :		Surface raw water					Groundwater	
(from actual release)		West-1	West-2	East-1	South	Retr. flow	GW	Total
	(in m3/s)	31.00	7.00	75.00	5.90	6.00	4.00	128.90

Fraction of flow	w3-sr/w1-3	w5-tng/w4-5	e1-2/e1	e2-3/e12	e3-jkt/e2-3	e4-5/e1-4	e4-bo-n/e4-5	e5-jkt/e4-5	s2-boe/s2
Fract. estimation	0.486	0.000	0.430	0.503	0.000	0.873	0.042	0.513	1.000

River	Reservoir	Max. Release	Act. Release	Canal	Flows	Canal	Flows	Grounwater pumping:	
Ciujung:	Karian	15	15	**West :**		**East :**		max /location	
	Pasirkopo	7	7	W1-W3	31.00	E1-E2	32.22	(m3/s):	1
	Unregulated	9	9	W3-Ser	15.05	E2-Kar	16.02	(mgd):	22.83
Cidurian:	Tanjung	7	0	W3-W4	15.95	E2-E3	16.20	**City/Area:**	
	Cilawang	4	4	W2-W4	7.00	E3-Bks	16.20	**Bo-N :**	
	Unregulated	3	3	W4-W5	22.95	E3-Jkt	0.00	# of location:	1
Citarum:	Jatiluhur	50	50	W5-Tng	0.00	E1-E4	42.78	max (m3/s):	1
	* flow prediction	10	10	W5-Jkt	22.95	E4-E5	37.35	actual (m3/s):	1
	* drought mngmt.	10	10			E4-BoN	1.78	**Bo-E :**	
	* on demand irrigation	5	5	**South :**		E4-BoSE	3.66	# of location:	2
	* raised Cirata dam	15	0	S1-BoW	2	E5-Jkt	19.15	max (m3/s):	2
Cisedane:	Genteng	6.5	0	S2-BoW	0.00	E5-Tng	18.20	actual (m3/s):	2
	Unregulated	1.5	1.5	S2-BoE	1.50			**Bo-W :**	
	Salak canal	2	2	S3-BoE	2.00	**Return flow:**		# of location:	1
	downst.flow-W	3	3	S4-BoE	0.40	BoE-BoN	2.00	max (m3/s):	1
	downst.flow-E	1	1			BoE-R1	1.00	actual (m3/s):	1
Ciliwung :	upstream flow	2	2			BoW-R1	3.00		
	spring	0.4	0.4			R1-Tng	4.00		
	downst.flow	2	2						

Instruction : [green box] : decide water demands, actual release from reservoirs and groundwater wells
actual release from a reservoir will mean that the reservoir should be built or is ready there
[blue box] : enter the fraction estimation to find the best result

Note : Jatiluhur-Cirata-Saguling (E1) are the only existing reservoirs in the network right now, the others are need to be built.
Present West Tarum canal has max. capacity 24 m3/s, other conveyance systems are need to be built or through rivers

Result of the model can be summarized as follow:

a. Percentage of fulfillment of water demand for each demand cluster.
It is shown from the table that water demands for Jakarta, Tanggerang and Bekasi could be fulfilled 100% (see supply/demand (%) row in the table). The model could only supply about 87% to 90.9% for other demand clusters. As total water demand for Jabotabek, 95.2% of demand could be fulfilled.

b. Additional reservoirs that need to be built.
There are only 3 existing reservoirs in the east, at Citarum river system. There is no reservoir built yet in the west and the south. From column at actual release in the table D.1., it shows that there are actual releases from Karian, Pasirkopo, and Cilawang reservoirs. This means that reservoirs at those areas should be built. If actual release is equal to zero, no reservoir needs to be built. Operational management of the Citarum river system should include flow prediction, drought management and on-demand irrigation. There is no need to raise Cirata dam.

These data lead to information where reservoirs and the conveyance system are needed to be built to fulfill the water demand. Cost to build reservoirs and number of people need to be relocated are estimated based on these data, meanwhile cost of the conveyance system also depends on its flow capacity.

c. Groundwater flow is taken from no land-subsidence area (i.e., Bogor) up to the maximum available permit for each location.
d. Discharge flows in the conveyance system.
   In the table D.1., there is information of discharge flows of each section of the conveyance system (e.g., discharge flow at section E1-E2 is 32.22 m3/s, section E2-Kar is 16.02 m3/s, etc.). Information of these flows will lead to the determination of flow design capacity as well as the cost of each section of the conveyance system.
e. Information that is needed for other assessments.
   - Assessment for reliability of water supply is mostly depends on the level of fulfillment of raw water supply, although other factors such as management also influences. Since no data available, the level of fulfillment (percentage) of raw water supply is used to assess the reliability of water supply. The level of fulfillment of raw water supply is also used for assessing the reduction of health-risk for the poor, employment opportunity (i.e., fulfillment of industrial water demand will keep the industry runs and grows), support economic growth, support regional development, etc. If the water demands can be fulfilled 100% (or high percentage) and with strict regulation on groundwater management, it will lead to reduce of groundwater abstraction by the industry, then it will be followed by a reduction of draw-down of groundwater table, reduce of environmental damage. Water for the urban poor people will be more available, either come from water supply network or from their shallow wells that are often dry due to excessive groundwater abstraction.
   - The level of fulfillment of raw water supply for a particular demand cluster can also be used to assess the reduction of land-subsidence rate in some areas, the reduction of sea water intrusion, the reduce of groundwater pollution, etc.
   - Information of additional reservoirs that need to be built will lead to information of number of people need to be relocated, land-area and cost of land acquisition to build new reservoirs. In the era of democracy, moving a large number of people and take their land for building a new reservoir is not an easy job for the government with limited fund. There will be some people that influence the displaced people to ask for a high price for land compensation or oppose the project, and political difficulties will emerge. The information of additional reservoirs that need to be built is used to assess the political difficulties.
   - Information of additional reservoirs that need to be built, how many and their location is used to assess the ecological impact due to transbasin water transfer.

Raw surface water supply allocation as calculation result from supply_sim model is used as basic data to determine assessment of sub-criteria in the DSS of Integrated Decision-Making for raw urban water supply development.

Appendix D: LOGICAL ASSESSMENT

Logical assessment is used to assess alternative's performance of sub-criteria that have to be determined by inference or deductive logic, due to no available real data. Logical assessment applied here by the author is based on the method of propositional logic (Pshenichny et. al., 2003). Propositional logic describes the relations between statements, or propositions. These are expressed by narrative sentences of natural language (English, etc.). A statement is the sense of narrative sentence, is either true or false. These two characteristics are logical values of statements. Verbal expressions like "and", "or", "if…then", "either…or" and some others have the sense of logical connectives. Those statements that do not include logical connectives are termed as "simple", those that do are as "compound statements", or "compounds". Compounds also are true or false. Their logical values are determined, first, by the logical values of elementary statements, and second, by the logical connectives between them. Propositional logic studies the exact sense of these expressions and general laws of their usage.

D.1. Technique of Propositional Logic

Propositional logic uses an artificial language capable of revealing the logical structure of compound statements. The alphabet of this language includes three kinds of signs.

1. Propositional variables: h, i, j, k,…. h_1, j_1, h_2,…, h_n, …etc., expressing elementary statements.
2. Logical connectives:

2. Logical connectives:	$\supset$	: implication
	&	: conjunction
	$\vee$	: disjunction
	$\neg$	: negation
	$\equiv$	: equivalence
3. Technical signs:	"("	: left bracket, and
	")"	: right bracket.

The basic concept in propositional logic is the propositional formula. It is defined as follows.

1. Propositional variable is propositional formula (e.g., h is a formula).
2. If A is a propositional formula, then $\neg$A is a formula too.
3. If A and B are propositional formulae, then (A & B), (A $\vee$ B), (A $\supset$ B), and (A $\equiv$ B) are formulae too. A and B are called "metaletters".

4. (A & B), (A ∨ B), (A ⊃ B), (A ≡ B), and ¬A are not necessarily (h & i), (h ∨ i), (h ⊃ i), (h ≡ i), and ¬h correspondingly, but just principal schemes of formulae, in which another formulae of any length can occupy the places of A and B.

The connective expressed in this scheme is called the main connective of the propositional formula. Any part of a given propositional formula, which is a propositional formula itself, is called a sub-formula of this formula. By accepted convention, each connective, except negation, requires a pair of left and right brackets, though the entire formula may be not taken into brackets.

Pshenichny et.al. (2003) and Spielthenner (2008) said that if we want to know whether a standpoint or decision is validated well enough and is firmly supported by data and general concepts, we need to check it for deducibility from what we take for premises (i.e. these data and concepts). This task is the same as strict proof and inference of statements that is elaborated well in propositional logic. If the given statement is “deducible” (or can be inferred) from some set of statements, the question arises whether it is possible to infer its negation from the same set. If not, then this set of statements is called self-consistent and valid for reasoning. If yes, it is inconsistent and requires correction (adding, removal or re-formulation of the statements).

D.2. Assessment for deducibility

Pshenichny et.al. (2003) explained that assessment for deducibility and self-consistency can be made by logical calculus. Logical calculus is a transformation or a succession of transformations of formulae in accordance with some rules of inference, which reveals that formula B follows from formulae A1, A2, …., A_n. (As before, A, B and other capital letters are “metaletters”, meaning any kind of propositional formula.) This means that B has the value “true” if and only if each of A1, A2, …, A_n has the “true” value. Logical consequence is denoted A1, A2, …, A_n → B. Formulae A1, A2, …, A_n are called premises, and B is called consequence.

Reduction to normal forms is the simplest calculus, in which there is one premise and the only kind of rules of inference is equivalent substitution. In trivial cases, so-called principal and shortened conjunctive and disjunctive normal forms help find all consequences (conjunctive forms) and hypotheses (disjunctive forms) of given formulae. However, if the case is more than one assumption (this is the most cases), more powerful calculi (sequential, natural-sequential and others) with specific rules of inference apply.

Example of strict inference of natural-sequential calculus is described below.

1. Sequence is expression A1, A2, …, Am → B, where A1, A2, …, Am, B are propositional formulae. Formulae A1, A2, …, Am are front members of the sequence, and B is the back member. There may be no front members at all, but the back one must always be present: → B.

2. Inference in natural-sequential calculus consists of a number of sequences. Each of these either is ‘main sequence’ or is derived from a previous one by a structural

transformation or a rule of inference. The last sequence of an inference has no front members and its back member is a finite formula.

3. There are two types of main sequences, called ‘logical’ and ‘mathematical’ ones. A logical main sequence is a sequence of general form C → C, where C is a propositional formula (this sequence arises if the inference is based on assumption expressed by C). A mathematical main sequence is a sequence of general form → D, where C is an axiom of mathematics.

4. Allowed structural transformations (for propositional logic; a horizontal line means that the below sequence follows from the above sequences).
   4.1. Transposition of two front members:
   $$\frac{C, D, \Gamma \to \Delta}{D, C, \Gamma \to \Delta}$$
   4.2. Withdrawal of a front member, which is the same as another front member :
   $$\frac{C, C, \Gamma \to \Delta}{C, \Gamma \to \Delta}$$
   4.3. Addition of any propositional formula to front members:
   $$\frac{\Gamma \to \Delta}{C, \Gamma \to \Delta}$$

5. Rules of inference (for propositional logic).
   Let A, B and C denote any propositional formulae and Γ, Δ and Θ any (possibly empty) lists of formulae divided by commas. The formulae of these lists are front members of some sequences. The following rules of inference of natural-sequential calculus are applicable to propositional logic.

   Rule 1 : Introduction of conjunction
   $$\frac{\Gamma \to A \qquad \Delta \to B}{\Gamma, \Delta \to (A \,\&\, B)}$$

   Rule 2 : Elimination of conjunction
   $$\frac{\Gamma \to A \,\&\, B}{\Gamma \to A} \qquad\qquad \frac{\Gamma \to A \,\&\, B}{\Gamma \to B}$$

   Rule 3 : Introduction of disjunction
   $$\frac{\Gamma \to A}{\Gamma \to A \vee B} \qquad\qquad \frac{\Gamma \to B}{\Gamma \to A \vee B}$$

   Rule 4 : Elimination of disjunction
   $$\frac{\Gamma \to A \vee B \qquad A, \Delta \to C \qquad B, \Theta \to C}{\Gamma, \Delta, \Theta \to C}$$

Rule 5: Introduction of implication

$$\frac{A, \Gamma \rightarrow B}{\Gamma \rightarrow A \supset B}$$

Rule 6: Elimination of implication

$$\begin{array}{lcl} \Gamma & \rightarrow & A \\ \Delta & \rightarrow & A \supset B \\ \hline \Gamma, \Delta & \rightarrow & A \end{array}$$

Rule 7: Introduction of negation

$$\begin{array}{lcl} A, \Gamma & \rightarrow & B \\ A, \Delta & \rightarrow & \neg B \\ \hline \Gamma, \Delta & \rightarrow & \neg A \end{array}$$

Rule 8 : Elimination of double negation

$$\frac{\Gamma \rightarrow \neg\neg A}{\Gamma \rightarrow A}$$

In the above expressions, the symbols put to the left of the arrow can be regarded as the 'memory' of the inference, and those to the right are its 'working part'.

D.3. Example of Application of Logical Assessment

Logical assessment is used to estimate performance that is difficult to be graded by a number. Example of the use of logical assessment to estimate performance of "reduction of land-subsidence's rate" with grading "very-possible/possible/little-possible " is presented here.

Let us denotes statements or compound statements as below:

h : There are three causes that make land-subsidence happen, geotectonic activity, the load of structures (e.g., building, bridge, etc.), and groundwater abstraction. The type of land-subsidence caused by the load of structures tends to be relatively local. The type of land-subsidence caused by groundwater abstraction is likely to spread more over a larger area, because pressure disturbance within the groundwater tends to propagate easily in horizontal direction.

i : Excessive groundwater abstraction in Jakarta is considered mostly caused by industries (including 4-5 star hotels), due to lack of water supply provided.

j : Based on DGWR's study in 1992, up to 1 meter of land-subsidence during the period of 1978 – 1990 in Jakarta is mostly caused by excessive groundwater abstraction. That time period is in the same year when a lot of industries were emerging in Jakarta.

k : Reduction on groundwater abstraction can reduce most of land-subsidence's rate in Jakarta.

l : Reduction on groundwater abstraction can be achieved by:
- providing enough water supply (comes from surface water) with unit price

that is cheaper than that of groundwater.

- having groundwater users/consumers convert to use surface water supply by applying strict regulation & high tax on groundwater.

m : Level of reduction of land-subsidence's rate depends on how much reduction on groundwater abstraction.

n : Industries, including 4-5 star hotels, are considered as the biggest consumers of groundwater abstraction.

o : Industries as business companies tend to get profit as much as possible. So, they tend to convert to use surface water, if it is enough water supply provided, and its unit price is cheaper than that of groundwater.

p : The Government provided enough water supply from surface water for the areas of land-subsidence in Jabotabek (i.e., Jakarta, Tanggerang, and Bekasi).

q : The Government applied strict regulation & high tax on groundwater abstraction, so that unit price of water supply comes from groundwater becomes more expensive than that from surface-water.

r : There will be a reduction on the rate of land-subsidence.

s : Assessment of performance of reduction of land-subsidence's rate is based on using index: "very-possible/possible/little-possible".

t : With referring to "percentage of fulfillment" of surface water supply to water demand in the areas of land-subsidence of Jabotabek (i.e., Jakarta, Tanggerang, Bekasi), performance of reduction of land-subsidence's rate can be categorized as:
"very-possible" if "% of fulfillment" > 95% for areas get impact most;
"possible" if 95% ≤ "% of fulfillment" < 85% for areas get impact most; and
"little-possible" if "% of fulfillment" ≤ 85% for areas get impact most.

u : Percentage of fulfillment of surface water supply to water demand in the areas of land-subsidence for Alternative: A-1 is 84%; A-2 is 100%; A-3 is 100%; and A-4 is 100%.

v : Reduction of land-subsidence's rate for Alternative: A-1 is "little-possible"; A-2 is "very-possible"; A-3 is "very-possible"; and A-4 is "very-possible".

Based on statements above, we can check logical values (true or false) of the assumptions and formulate logical inferences that lead to the conclusion.

$h \rightarrow h$
$i \rightarrow i$
$j \rightarrow j$
$k \rightarrow k$
$l \rightarrow l$
$m \rightarrow m$
$n \rightarrow n$
$o \rightarrow o$
$p \rightarrow p$
$q \rightarrow q$
$r \rightarrow r$ (statements or assumptions: h, i, j, …, and r have true values).

$$((h \,\&\, i) \,\&\, j) \supset k \qquad \text{(inference 1)}$$

(statement k is implication from combination of statements h, i and j).

((k & l) ⊃ p (inference 2)
(statement p is implication from combination of statements k and l)

((k & l) ⊃ q (inference 3)
(statement q is implication from combination of statements k and l)

((k & m) & (i & n & o) & (p & q)) ⊃ r (inference 4)
(statement r is implication from combination of statements k, m, i, n, o, p and q)

((r & s) & (t & u)) ⊃ v (inference 5)
(statement v is implication from combination of statements r, s, t and u)

((r & s) & (t & u)) , v → v (conclusion)
(Reduction of land-subsidence's rate for Alternative: A-1 is "little-possible"; A-2 is "very-possible"; A-3 is "very-possible"; and A-4 is "very-possible").

D.4. Application of Logical Assessment in the DSS

Logical assessment is used to estimate performance that cannot be graded by a number (e.g., "very-possible/possible/little-possible", etc). The performance is used as an input data for the matrix evaluation of alternative's performance vs. sub-criteria, in which all of them become input data for MCDA analyzing of the DSS. Applications of the use of logical assessment to estimate performance of sub-criteria in this study are presented here:

1. Reduction of land-subsidence's rate

h : There are three causes that make land-subsidence happen, geotectonic activity, the load of structures (e.g., building, bridge, etc.), and groundwater abstraction. The type of land-subsidence caused by the load of structures tends to be relatively local. The type of land-subsidence caused by groundwater abstraction is likely to spread more over a larger area, because pressure disturbance within the groundwater tends to propagate easily in horizontal direction.
i : Excessive groundwater abstraction in Jakarta is considered mostly caused by industries (including 4-5 star hotels), due to lack of water supply provided.
j : Based on DGWR's study in 1992, up to 1 meter of land-subsidence during the period of 1978 – 1990 in Jakarta is mostly caused by excessive groundwater abstraction. That time period is in the same year when a lot of industries were emerging in Jakarta.
k : Reduction on groundwater abstraction can reduce most of land-subsidence's rate in Jakarta.
l : Reduction on groundwater abstraction can be achieved by:

- providing enough water supply (comes from surface water) with unit price that is cheaper than that of groundwater.
- having groundwater users/consumers convert to use surface water supply by applying strict regulation & high tax on groundwater.

m : Level of reduction of land-subsidence's rate depends on how much reduction on groundwater abstraction.

n : Industries, including 4-5 star hotels, are considered as the biggest consumers of groundwater abstraction.

o : Industries as business companies tend to get profit as much as possible. So, they tend to convert to use surface water, if it is enough water supply provided, and its unit price is cheaper than that of groundwater.

p : The Government provided enough water supply from surface water for the areas of land-subsidence in Jabotabek (i.e., Jakarta, Tanggerang, and Bekasi).

q : The Government applied strict regulation & high tax on groundwater abstraction, so that unit price of water supply comes from groundwater becomes more expensive than that from surface-water.

r : There will be a reduction on the rate of land-subsidence.

s : Assessment of performance of reduction of land-subsidence's rate is based on using index: "very-possible/possible/little-possible".

t : With referring to "percentage of fulfillment" of surface water supply to water demand in the areas of land-subsidence of Jabotabek (i.e., Jakarta, Tanggerang, Bekasi), performance of reduction of land-subsidence's rate can be categorized as:

"very-possible" if "% of fulfillment" $> 95\%$ for all areas;
"possible" if $95\% \leq$ "% of fulfillment" $< 80\%$ for all areas; and
"little-possible" if "% of fulfillment" $\leq 80\%$ for all areas.

2. Reliability of water supply source :

h : Reliability of water supply source is a level of ability to supply water from any available source whenever it is needed.

i : Available water supply source comes from reservoir's release, unregulated river flows, springs, and return flows. Groundwater flow is not included in order to reduce excessive groundwater extraction that caused environmental damages.

j : River flows fluctuate from time to time depends on seasons (i.e., dry & wet season) so that getting water from unregulated flows (e.g., directly from river flows, with no reservoir) to supply urban water becomes not reliable.

k : Water supply comes from reservoir's release depends on reservoir operation and water demand, so that it is more controllable than water supply from any other source.

l : Water supply comes from reservoir's release is a reliable water supply source.

m : Assessment of performance of reliability of water-supply source is based on using index: "bad/fair/good/very-good/excellent".

n : With referring to total water demand, performance of reliability of water-supply source can be categorized as:

"bad" if q total $\leq 70\%$ and q resv. $\leq 50\%$;

“fair” if 70% < q total ≤ 80% and 50% < q resv. ≤ 65%;
“good” if 80% < q total ≤ 90% and 65% < q resv. ≤ 75%;
“very-good” if 90% < q total ≤ 95% and 75% < q resv. ≤ 85%; and
“excellent” if q total > 95% and q resv. > 85%;

3. Irrigation water from new built reservoir :

   h : some of urban water supplies come from new built reservoir.
   i : Almost all of the new built reservoirs release water urban water supply and irrigation water, since based on the previous masterplan, their location is in the proposed reservoir for irrigation water.
   j : How much irrigation water from new built reservoir depends on how many reservoirs are built in this water development project and the reservoir's location.
   k : Assessment of performance of irrigation water from new built reservoir is based on using index: “not-significant/some/significant”.

4. Average raw water quality:

   h : Quality of raw water supply depends on its water diversion (i.e., through reservoir or unregulated flow), reservoir's location (i.e., at upstream or downstream of river system), and the conveyance system to demand center (i.e., by open canal or pipe).
   i : Quality of raw water supply comes from reservoir tends to be better than that from unregulated flow, since reservoir silts sediment brought by river flow.
   j : Reservoir at downstream of river system receives return flows from urban/industrial center and agricultural land in the upstream river system. It will make its water quality is worse than reservoir at upstream.
   k : When it passes through urban center, open canal carrying water supply tends to get pollution, so that its water quality will be worse than that carried by pipe.
   l : Assessment of performance of average raw water quality is based on using index: “bad/fair/good/very-good/excellent”.

5. Reduce spread of groundwater pollution:

   h : Since groundwater abstraction leaves empty pores in underground soils, its condition causes polluted groundwater that infiltrated at nearby area moves to fill in the empty pores.
   i : Excessive groundwater abstraction leaves more empty pores in underground soils, so that it causes more spread of groundwater pollution.
   j : Spread of groundwater pollution in Jakarta is mostly caused by excessive groundwater abstraction.
   k : Spread of groundwater pollution's rate in Jakarta can be reduced by reducing groundwater abstraction.
   l : Level of reduction of spread of groundwater pollution's rate depends on:

- how much reduction on groundwater abstraction, which is influenced by water supply provided and government's policy (e.g., high tax & strict regulation on groundwater, etc.).
- how far location of pollution infiltrated to ground water (e.g., polluted river flows, etc.) from the location of excessive groundwater abstraction.
- how far location of urban centers from industrial centers.

m : Industries, including 4-5 star hotels, are considered as the biggest consumers of groundwater abstraction, due to lack of water supply provided.

n : Industries as business companies tend to get profit as much as possible.

o : A lot of industries tend to convert to use surface water, if it is enough provided, with good quality, and is cheaper than groundwater.

p : The Government provided enough water supply from surface water for Jabotabek.

q : The Government applied high tax & strict regulation on groundwater abstraction.

r : With high tax on ground water, price of water supply from groundwater becomes more expensive than that from surface-water.

s : There will be a reduction on the rate of spread of groundwater pollution.

t : Assessment of performance of reduction of seawater intrusion's rate is based on using index: "very-possible/possible/little-possible".

6. Ecological impact due to transbasin water transfer :

h : Ecological impact due to transbasin water transfer depends on its natural condition of the river system, how much amount of water will be diverted from its original river basin, location of habitat for endangered species, how many new reservoirs will be built, location of proposed new reservoirs, etc.

i : Reservoir holds sediments from upstream flows, so that river flows in the downstream and estuary will be lack of sediment discharge. This condition changes the balance of natural processes in the downstream river and its estuary that endanger biological lives in those areas (e.g., small shrimps, small fishes, birds, etc.).

j : Location of new reservoirs that closed to location of habitat for endangered species will increase the ecological impact.

k : The more new reservoirs will be built and the more amount of water will be diverted from its original river basin will cause more ecological impact due to transbasin water transfer.

l : Assessment of performance of ecological impact due to transbasin water transfer is based on using index: "few/some-2/many".

7. Political difficulties :

h : Political difficulties in this water supply development project are mostly come from the impact of building new reservoirs (e.g., people do not want to be relocated from location of proposed new reservoir due to cultural reason, opposition environmental groups, the high land acquisition cost due to rapid increase of land price in that area, etc.)

i : The size (i.e., large) of inundated areas and its location (e.g., it is closed to village or not) of proposed reservoir will determine how large land acquisition is needed, its cost, and how many people need to be relocated.

j : The more people need to be relocated will stimulate mass-media to report it in the news, so that it will stimulate emerging of social issues (e.g., people are not willing to leave, unit price for their land is too low, etc.), and it will stimulate more opposition from environmental & social concern groups.

k : The more people need to be relocated will cause more political difficulties.

l : As public hear about the project location (e.g. new reservoir), land price in project area will increase very high or some people are not willing to leave.

m : The larger size of inundated areas will cause more fund needed for land acquisition cost.

n : The closer location of proposed reservoir's inundated areas from urban center (e.g., village, etc.) will cause the more expensive of land price per unit area. Thus, it will increase the land acquisition cost.

o : In this case, there should be a political approach to regulate the land price and to move the people living in the proposed project area, since there is always be a limitation for land acquisition cost of every development project.

p : The more fund needed for land acquisition cost causes the more political difficulties.

q : Assessment of performance of political difficulties is based on using index: "few/some-2/many".

8. Employment opportunity :

h : Employment opportunity in this case depends on the level of fulfillment of industrial water demand that support the life and growth of industry.

i : Assessment of performance of employment opportunity is based on using index: "bad/fair/good/very-good/excellent".

9. Support sustainability of water quantity :

h : Condition that support sustainability of water quantity depends on the level of fulfillment of water demand from surface water, the land-use conditions that support water infiltration/recharging process in the river basin, and the amount of groundwater abstraction.

i : Recharging process of groundwater takes a long time due to slow water movement through soil pores. So, excessive groundwater abstraction will not support sustainability of water quantity.

j : The more amount of groundwater abstraction will make worse in supporting sustainability of water quantity.

k : The higher the level of water demand fulfillment from surface water will reduce the groundwater abstraction. Thus, it will make better in supporting sustainability of water quantity.

l : The better land-use conditions in supporting water infiltration/recharging process in the river basin will make river flows more constant. Thus, it will give more support for sustainability of water quantity.

m : Assessment of performance of support sustainability of water quantity is based on using index: “not-significant/some/significant”.

Appendix E: PROCEDURE FOR THE DSS OF IDM MODEL

E.1. General Procedure

The general procedure of decision support system model for integrated planning development on raw water supply in this study covers:

1. Identify the problem that happened, identify all possible solutions; define the goals or objectives that want to be achieved.
2. Identify facts, assumptions, constrains, consequence of either action or do nothing, and identify decision-maker groups, parties and participants in the decision-making process.
3. Develop framework for integrated decision-making process.
4. Establish criteria (and sub-criteria if needed) be considered in the in the integrated planning process. Based on the entire system related to raw water supply development, view outward for all possible criteria/sub-criteria for the development. From the defined criteria/sub-criteria, view inward to see whether all criteria/sub-criteria cover everything needed for evaluation
5. Define and select all available alternative solutions to be considered.
6. Based on the selected alternatives, refine the criteria and sub-criteria. Check whether any action from selected alternatives will give impacts that should be considered and added in the evaluation of alternatives.
7. Determine the relative importance among the criteria/sub-criteria.
8. Determine the performance of each alternative based on system analysis process for each criteria/sub-criteria.
9. Convert the performance scores to a common rating scale.
10. Apply MCDA technique to rank the alternatives.
11. Adjust the weights among the criteria/sub-criteria as appropriate.
12. Consider ranking based on viewpoints of various decision-making groups or stakeholders.
13. Use overall result (average score & standard deviation) to find the best alternative.

E.2. MCDA Procedure

Multi Criteria Decision Analysis (MCDA) in the DSS of IDM is a systematic process for analyzing discrete decision based on the concept of overall score for an alternative. The process begins with:

a. Define a common rating scale (0 to 1, 1 to 5, 1 to 10, etc.) and convert the performance of alternatives in any sub-criteria into the rating.

b. Determine the relative importance factor for each criteria (and sub-criteria, if it is needed). Relative importance factor discussed here is the ratio of the importance of each criteria compared to each others, or among the sub-criteria within each criteria. Then, the relative importance factor is normalized both for total and within each criteria. The DSS here provides: (i) five sets of relative importance factor for criteria (i.e., in G1, G2, ...G5), and (ii) two sets of relative importance factor for sub-criteria (i.e., case-1 and case-2). The relative importance factors in G1 to G5 are chosen to represent viewpoints of five decision-making groups that is formed from stake-holders and responsible agencies. Meanwhile, the relative importance factors in case-1 and case-2 are provided in anticipation in case if there is different opinion/consideration in deciding the importance factor of the sub-criteria.
c. Using Matrix Evaluation of performance of alternatives vs. sub-criteria as input data, analyzing process in this DSS uses four MCDA techniques: WAM (weighted average method), CP (compromise programming), Promethee WAM, and Promethee method. WAM is the simplest method using weighted average score of performance to find the overall score for an alternative. CP method uses an approach that identifies solution closest to the ideal one by some distance measure. The DSS provides three options for exponent number (i.e., p) for the metric of CP method, there are: $p = 1$, $p = 2$ and p = any big number closed to infinity. The purpose of using $p > 1$ is to give more emphasis on the better rating different among alternative's performances (e.g., $0.9^2 = 0.81$, $0.2^2 = 0.04$). Promethee method is outranking comparison with indifference range for both the main criteria and sub-criteria. Every of alternative's performance in criteria/sub-criteria is compared pair-wise to each of the other alternatives. Meanwhile Promethee WAM method applied here is outranking comparison using Promethee method with indifference range for the main criteria combined with the WAM for the sub-criteria.
d. Try one set of relative importance factors for criteria (e.g., G1) and sub-criteria (e.g., case-1). Run with one of MDA techniques provided (e.g., WAM) and record the result. Result of this step is ranking of alternatives based on viewpoint of decision-making group G1. Try to use other viewpoint of decision-making groups (e.g., G2, G3, etc.) and record the results.
e. Combine results from all decision-making groups from one MDA technique/ method, and then, perform sensitivity analysis. Result of this step is average score, standard deviation, and ranking of each alternative. Standard deviation represents the sensitivity of determining ranking of alternatives.
f. Combine results from all decision-making groups from all MDA techniques/ methods, then, perform sensitivity analysis. Result of this step is average ranking, standard deviation, and ranking of each alternative.
g. If it is needed, adjust the relative importance factor for criteria/sub-criteria, then perform step (e) and (f) above. The result of this step is average rank, standard deviation, and final ranking of each alternative.

E.3. MCDA Techniques

E.3.1. Weighted Average method

This is the simplest method to find the best alternative by using method as below:

$$\max_{j= ,n} \quad S_j$$

$$S_j = \sum_{1} \quad W_i * R_{i,j}$$

in which: S_j : score of alternative's performance
$R_{i,j}$: score of performance based on each criterion
W_i : normalized weight of criterion i

E.3.2. Compromise Programming method

Compromise programming uses an approach that identifies solution closest to the ideal one by some distance measure. The best alternative is fund as below:

$$\max_{j= ,n} \quad S_j$$

$$S_j = \sum_{1} \quad W_i * R_{i,j}$$

$$R_{i,j} = \left[\frac{A_{i,j} - W_i}{B_i - W_i} \right]^p$$

in which : $A_{i,j}$: actual performance of an alternative
B_i : best performance among alternatives in one criterion
W_i : worst performance among alternatives in one criterion
p = 1, 2, or large number

E.3.3. Promethee method

Promethee method is an outranking method that consists of a compromise between the poor dominance relations and the excessive ones generated by utility functions.

Every outranking method includes 2 phases:

- the construction of an outranking relation,
- the exploitation of this relations in order to assist the decision maker

We will consider a particular exploitation of the valued outranking relation, especially for case in which the actions have to be ranked from best to weakest. The Promethee-I method provides a partial ranking of the actions. If needed, Promethee- II can obtain a complete ranking.

Construction of an outranking relation :

Let discuss preference functions we use in this method. The associated preference function $P(a,b)$ of a with regard to b will be define as:

$$P(a,b) = 0 \qquad if\ f(a) \leq f(b)$$
$$= p[f(a, f(b)] \quad if\ f(a) > f(b)$$

in which : a and b are two particular actions of K, a set of possible solutions

$$p[f(a, f(b)] = p[f(a) - f(b)]$$

In order to indicate clearly the areas of indifference in the neighborhood of $f(b)$, we write: $x = f(a) - f(b)$ and we represent graphically the function $H(x)$ so that:

$$H(x) = P(a,b), \quad x \geq 0$$
$$= P(a,b), \quad x \leq 0$$

There are six types of preference functions used as bellow:

Type 1 : Usual Criterion :

$$p(x) = 0, \qquad x \leq 0$$
$$= 1, \qquad x > 0$$

If the decision-maker identifies the criterion f(.) as type I, no particular parameter has to be defined.

Type 2: Quasi Criterion:

$$p(x) = 0, \qquad x \leq l$$
$$= 1, \qquad x > l$$

When the decision-maker identifies the criterion f(.) as type II, only the parameter l has to be defined.

Type 3: Criterion with Linear Preference :

$$p(x) = x/m, \qquad x \leq m$$
$$= 1, \qquad x \geq m$$

An extension of the notion of criterion allows the decision-maker to prefer progressively a to b for progressively larger deviations between f(a) and f(b). The intensity of preference increases linearly until this deviation equals m, after this value the preference is strict. If the decision-maker considers that a particular criterion is of Type III, he has only to define the value m from which strict preference is considered

Type 4: Level Criterion :

$$p(x) = 0, \qquad x \leq q$$
$$= ½, \qquad q \leq x \leq (q+p)$$
$$= 1, \qquad x \geq (q+p)$$

In this case, a and b are considered as indifferent when the deviation between $f(a)$ and $f(b)$ does not exceed q, between q and $q + p$ the preference is weak (1/2), after this value the preference becomes strict.

Type 5: Criterion with Linear Preference and Indifference Area :

$$p(x) = \begin{cases} 0, & x <= s \\ (x-s)/r, & s \leq x \leq (s+r) \\ 1, & x \geq (s+r) \end{cases}$$

In this case the decision-maker considers that *a* and *b* are completely indifferent as long as the deviation between *f(a)* and *f(b)* does not exceed *s*. Above this value the preference grows progressively until this deviation equals *s+r*. Two parameters have to be defined when a particular criterion has been identified as being of this type.

Type 6: Gaussian Criteria :

$$p(x) = \begin{cases} 0, & x \leq 0 \\ 1-e^{-x2/2\sigma 2}, & x \geq 0 \end{cases}$$

If a particular criterion is of the Gaussian type, the preference of the decision-maker still grows with the deviation *x*. The value of σ may be easily fixed according to the experience obtained with the Normal Distribution in Statistics.

Figure F.1. shows the six types of preference functions used in Promethee :

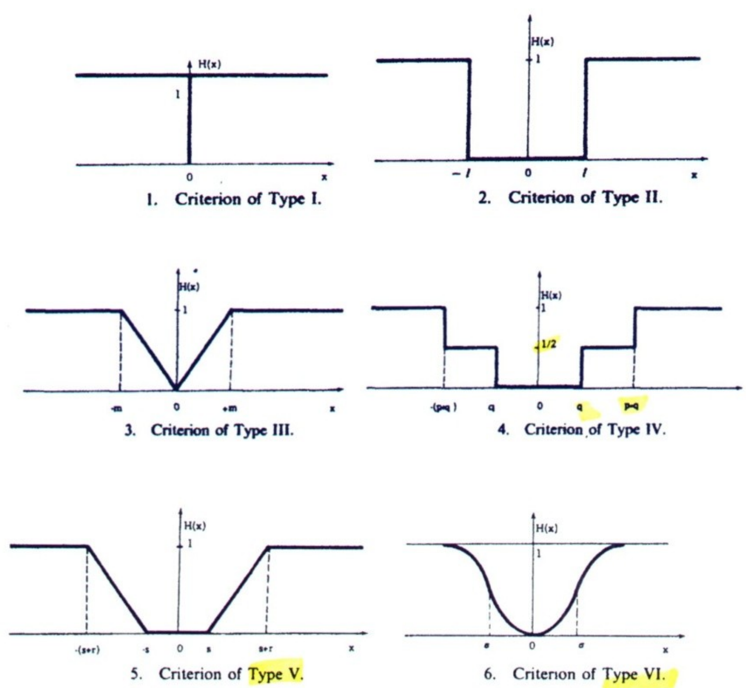


Figure E.1. Types of preference functions used in Promethee method

When a multi criteria problem has to be treated, the decision-maker has to decide which of the different criteria types he should use and the value of the possible corresponding thresholds (e.g., *l, m, p, q, r*, and *s*). The nature of the criteria and the value of the thresholds can be fixed according to the economic meaning attached to them in each particular case. The six types of criteria above are considered sufficient to treat most of the cases encountered in practice.

For each couple of actions *a, b* as part of *K,* we first define a preference index for a with regard to *b* over all the criteria. Suppose every criterion has been identified as being of one of the six types considered so that the preference functions $P_h(a, b)$ have been defined for each *h* - 1,2,..., *k* . Let define a preference index as:

$$\pi_{(a,b)} = \frac{1}{k}\sum_{h=1}^{k} P_h\ (a,b)$$

This index gives a measure of the preference of *a* over *b* for all the criteria: the closer to 1, the greater the preference. Of course, other indices could possibly be considered. For example, we suppose here that all the criteria have the same importance. If it is not the case, one can introduce a weighted preference index.

A value outranking graph is a graph that represent the dominance of alternatives in which the arc $_{(a,b)}$ has the value $\pi_{(a,b)}$. The original dominance graph has thus been considerably enriched. If *a* dominates *b,* $\pi_{(b,a)} = 0$, but $\pi_{(a,b)}$ is not necessarily equal to 1 because *a* can be better than *b* for each criterion without the preference being strict.

Exploitation of the relations:

To select the best actions in *K*, the decision-maker need to determine in *K* a set of good alternative actions, and rank the actions, by either partial or total preorder. With considering the values of outranking graph, for each node, the outgoing flow :

$$\emptyset^{+}(a) = \sum_{x\, \in K} \pi_{(a,x)}$$

and the incoming flow:

$$\emptyset^{-}(a) = \sum_{x\, \in K} \pi_{(x,a)}$$

The larger $\phi^{+}(a)$, the more *a* dominated the other actions of K. The smaller $\phi^{-}(a)$, the less *a* is dominated. Let we define the two total preorder (P^{+}, I^{+}) and (P^{+}, I^{+}) such that:

$a\ P^{+}\ b$	iff	$\phi^{+}(a) > \phi^{+}(b)$,
$a\ P^{-}\ b$	iff	$\phi^{-}(a) > \phi^{-}(a)$,
$a\ I^{+}\ b$	iff	$\phi^{+}(a) = \phi^{+}(b)$,
$a\ I^{-}\ b$	iff	$\phi^{-}(a) = \phi^{-}(a)$,

Suppose a total preorder (complete ranking without incomparability) has been requested by the decision-maker. We then can consider for each action *a* part of *K* the net-flow:

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a)$$

with this equation, we can easily be used for ranking the actions as follow,

a outranks ***b*** *(a P b)*	iff	$\phi(a) > \phi(b)$
a indifferent to ***b*** *(a P b)*	iff	$\phi(a) = \phi(b)$

All the actions of *K* are now completely ranked as in Promethee II, the complete ranking relation.