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Title of the paper

A Model Based Approach to Adaptive Urban Water Security Management

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ABSTRACT

Water security indexes stimulate investments in water management. They are, however, not developed to support planning of these investments under the uncertain conditions encountered in urbanizing deltas. We therefore develop an approach to combine water security indexes and fast integrated modelling in support of Adaptive Urban Water Security Management. This paper develops a model underlying this approach. It integrates the Asian Water Development Outlook water security index in to a System Dynamic model of urban water management in Jakarta. We conclude that this model is fast and can simulate development of the water security indicators for an urban water system, but is still weak in incorporating sufficient spatial resolution. Still it is promising for Adaptive Urban Water Security Management.

Keywords: model, urban water security, system dynamic, scenarios, planning

1. Introduction

Concept of water security has been developed from the 1990s onward and evolved significantly since then. It is discussed by policy makers and academics, including from Global Water Partnership, The World Economic Forum, UNESCO’s Institute for Water Education, and Asia-Pacific Water Forum in 2007(Cook and Bakker, 2012). The definition on water security is still growing and become contradiction (Zeitoun ; Lankford et al., 2016). Water security, however, mostly is said involves the access to enough water in acceptable quantity and quality of water at affordable cost for sustaining health, livelihoods, human well-being, ecosystems and socio-economic development (Global Water Partnership, 2000;Swaminathan, 2001;Grey and Sadoff, 2007;Donoso ; Di Baldassarre et al., 2012;UN Water, 2013), while ensuring that the natural environment as well as social justice are protected and enhanced (Global Water Partnership, 2000), and coupled with an acceptable level of water-related risks (floods, landslides, land subsidence, and droughts) (Grey and Sadoff, 2007;Donoso ; Di Baldassarre et al., 2012). More than that, it is also about resolving conflict of water dispute and the tension between the various stake holders who compete for limited resources (Van Beek and Arriens, 2014).

Assessment of water security is important and need more attention in the years ahead. It evaluates the status of the water system (Cook and Bakker, 2012). The Asian Water Development Outlook (AWDO) Framework facilitates the assessment and comparison of the water systems status using water security index. Especially for urban water security, the assessment of water security index is done based on four indicators; 1) access to piped water supply, 2) access to improve sanitation, 3) economic damage due to floods and storms, and 4) river health (Asian Development Bank, 2013).

Nonetheless these indicators are not developed to support the planning and implementation of the investment. To strengthen water security approaches in this respect, we propose to combine the urban water security indicators with modeling water system development, taking future uncertainties into account.

The model is needed to cope the uncertainties of socio-economic, political, and also policy changes to help assessing water security condition. It also should be comprehensive integrate the water security indicators and water system. Therefore, an integrated model is developed to explore the influence of possible uncertain futures to urban water security index. The model adopts system dynamic as its approach and uses VenSim as the software platform. System dynamic approach is applicable because it clarifies the problem under study, the behavior of the result model, and the effects of potential solutions (Akhtar, 2011). It also allows to conduct multi-scenario, multi analyses that resulting in comparisons of many strategies over time (Sehlke and Jacobson, 2005).

2. Methodological framework

2.1 Urban Water Security Assessment

2.1.1 Asian Water Development Outlook (AWDO) Framework

Water security can be assessed at national, river basin, city, and local scales (Van Beek and Arriens, 2014). There are two approaches to assess water security, which are the developmental approach and risk-based approach. The developmental approach intends to increase water security over time by identifying the outcomes through a combination of policies and projects, while the risk-based approach intends to increase water security by managing risks and reducing vulnerabilities resulting from climate variability and water-related disasters (Van Beek and Arriens, 2014). When uncertainties are taken into account, the risk-based approach may reduce the useful options, while developmental approach will broaden both uncertainties and analytical methods by which to integrate them (Zeitoun ; Lankford et al., 2016). Therefore, the research adopts the development approach to integrate both uncertainties and analytical method.

One of an outcome-based approach is developed by The Asian Development Bank (ADB) and the Asia-Pacific Water Forum, known as Asian Water Development Outlook (AWDO) Framework (Asian Development Bank, 2013;Van Beek and Arriens, 2014). It transforms the vision of water security into quantitative assessment in five key dimensions. The quantitative assessment is done in five key dimensions, as a transformation of water security for households, economies, cities/ urban, the environment, and resilient communities.

The urban water security index measures the progress of creating better urban services and management to develop vibrant, livable cities and towns (Asian Development Bank, 2013). The concept of urban water security index is based on the Water Sensitive Cities Framework, illustrated in figure below (Asian Development Bank, 2013).

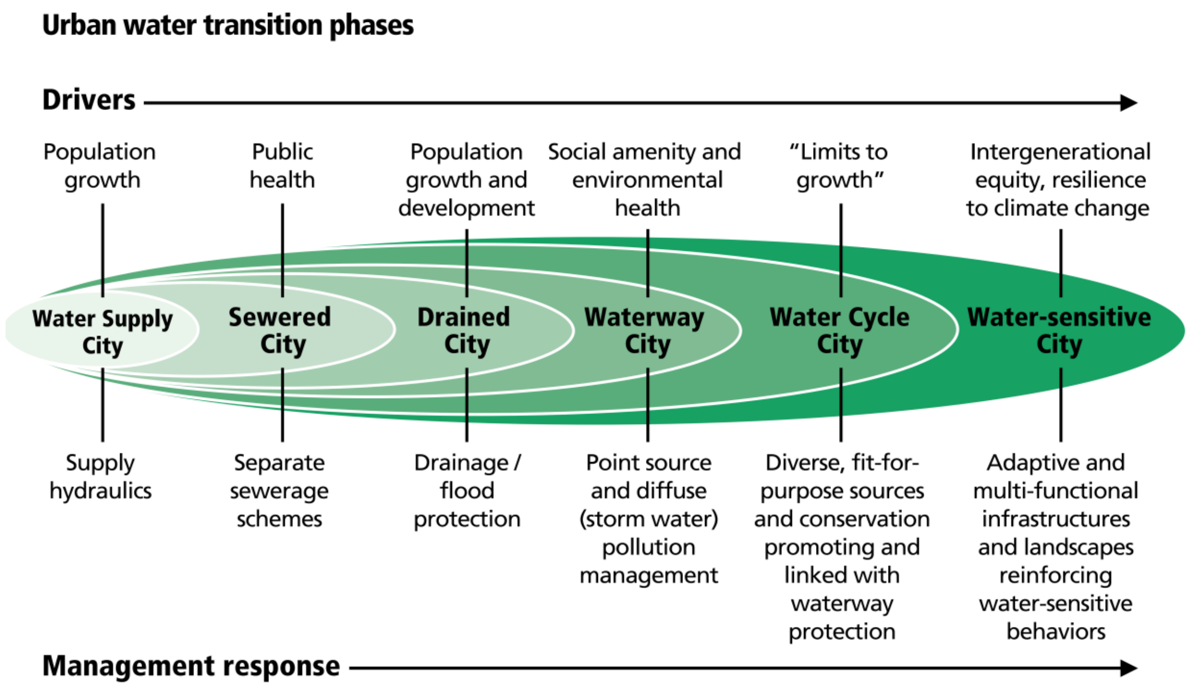

Figure 1 Water-Sensitive Cities Framework

Source: Based on T. Wong and R. R. Brown. 2009. The Water Sensitive City: Principles for Practice. Water Science and Technology 60(3):673–682

Based on this framework, the urban water security indicators are expressed as follow (Van Beek and Arriens, 2014;Asian Development Bank, 2016):

1. Access to piped water supply (%),
2. Access to improve sanitation (%),
3. Economic damage due to floods and storms, and
4. Adjustment factors; urban growth rate and river health.

2.1.2 The Arcadis Sustainable Cities Water Index (SCWI)

Arcadis first developed Sustainable Cities Index, which is contained of three pillars of sustainability; people, planet, and profit sub-index. Recently, Arcadis has developed an index focusing on water through three main elements, each with their own sub-indicators ; resiliency, efficiency, and quality (Arcadis, 2016).

A water resilient city means an ability of the city to protect its citizens and be adapted to recover quickly, against disasters such as flooding and drought, while ensuring that water-related services countinue undisrupted. The resiliency is indicated using the following indicators :

a. Water stress, as percentage of freshwater withdrawn to total available locally,
b. Green space, as percentage of city area covered with green space,
c. Water-related disaster risk, as number of different types of water-related natural disasters, including floods, storms, droughts, and mud flows,
d. Flood risk, as number of floods experienced between 1985-2011,
e. Water balance, as monthly deficits and surpluses of rainfall,
f. Reserve water, as reservoir capacity within 100 km of city, relative to total city water supply.

The second sub-index is efficiency. This sub-index measures how the cities effectively manage their water supply. It is assessed using the following indicators :

a. Leakage, as the proportion of water lost in transit, includes unbilled consumption, apparent losses, and physical leakage,
b. Water charges, as average cost per cubic meter of water to consumers, relative to average income in city,
c. Metered water, as percentage of households whose water consumption is metered,

d. Reused wastewater, as comparison of wastewater reuse to total wastewater produced,
e. Service continuity, as average hours per day over the whole network,
f. Sanitation, as percentage of households with access to improved sanitation,
g. Drinking water, as percentage of households with safe and secure drinking water.

In the Index, the performace of water quality is the highest. Many cities have recognized their critical role in improving quality of life, and have made signifcant investment in this sector. The quality sub-index assesses how the city can provide a clean and healthy water supply using the following indicators :

a. Sanitation, as percentage of households with access to improved sanitation,
b. Drinking water, as percentage of households using an improve drinking-water source,
c. Treated wastewater,a s percentage of wastewater treated,
d. Water-related disease, as incidence of water/ sanitation related disease per capita,
e. Threatened freshwater amphibian species, as percentage of freshwater amphibian species classified by the International Union for Conservation of Nature as threatened in an area,
f. Raw water pollution, as concentration of phosphorus and sediment yields from source,
g. Drinking water, as percentage of households with safe and secure drinking water.

This new framework aim to evaluate the urban ware based on the quality of their waterways and delivered water, the efficiency of their water system, and the resilience of their water defences and infrastructure. This index helps to guide future improvements, investment, and water sustainability.

2.1.3 Fast and Integrated modelling for Adaptive Urban Water Security Management

General Approach

The integrated model to support adaptive urban water security management will adopt developmental approach, especially water security framework of AWDO (Asian Development Bank, 2016), to assess urban water security index. To calculate urban water security index over time, the indicators of AWDO framework are more general and simpler. Moreover AWDO excludes governance valuation, so it gives the governance a chance to see the system clearly, and besides that it is not always easy to assess the performance of the government.

The key dimensions of water security are related and interdependent. While the indicator(s) in one dimension increases, it will simultaneously increases or decreases other indicator(s) in other dimension. However the assessment of water security in AWDO farework is based on statistical data, so the interrelation between the indicators cannot be seen explicitly. Nonetheless the interrelation of urban water security indicators approximately can be shown in following illustration.

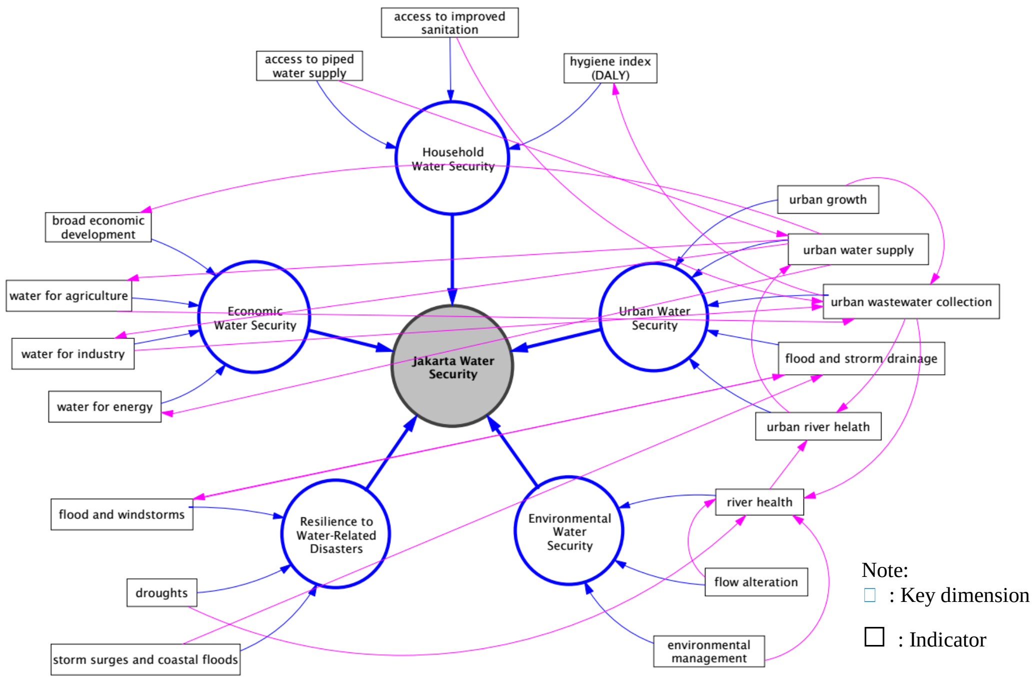

Figure 2 Interrelation of The Indicators of Water Security (Adopted from Asian Development Bank (2016))

The integrated model should be comprehensive integrate the water security indicators and water system. As water system It is greatly modified by urbanization, industrialization, population growth impacts on the environment and the need to provide water services, including water supply, drainage, wastewater collection and management, and beneficial uses of receiving waters (Marsalek ; Cisneros et al., 2008), the model should be cope with possible actions and run many long time series within limited computation time. Accordingly another challenge is to make the model as compact as possible and still can represent the overall conditions.

Integrated water system model will be developed using system dynamic (SD) approach. The System Dynamic approach is applicable because it can help to understand the system under study, the behavior of the resulting model, and the effects of potential solutions (Akhtar, 2011). It also allows to conduct multi-scenario, multi-attribute analyses that resulting in comparisons of many strategies over time (Sehlke and Jacobson, 2005).

3. Fast and Integrated Model for Adaptive Urban Water Security Management in Jakarta

3.1 Study Area

This integrated model is a simplified model to experiment with preliminary idea and elaborate the method and framework. The real case is located in Jakarta Province, Indonesia.

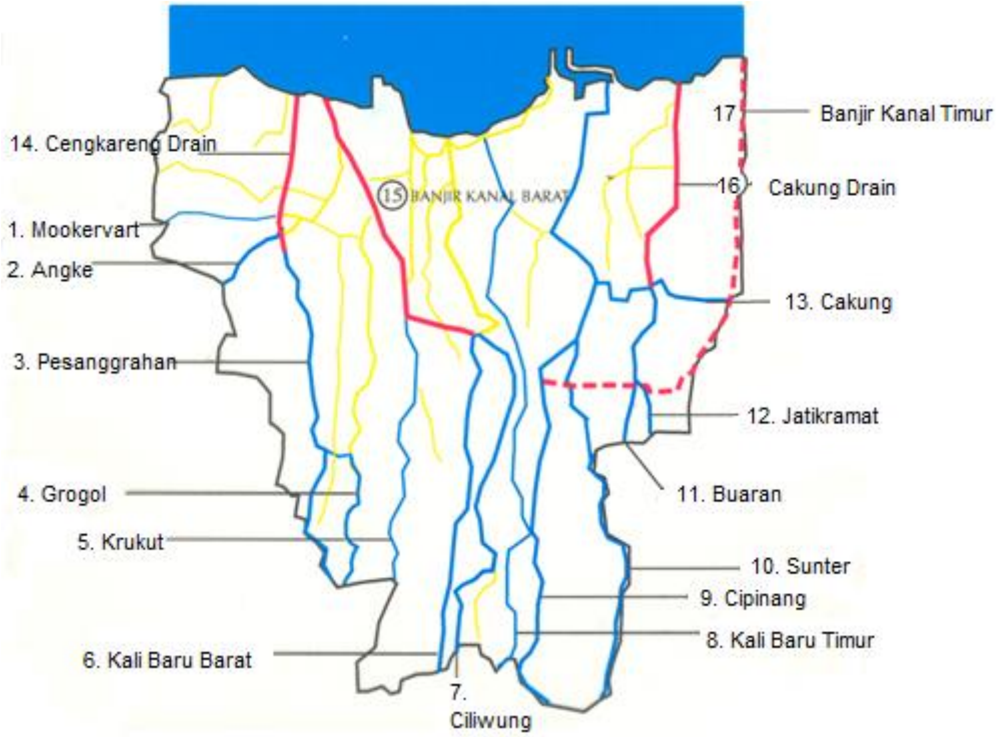

Figure 3 Map of 13 Rivers in Jakarta, Indonesia (Source: PUSAIR)

Based on the data from PAM Jaya (public water company in Jakarta), in 2015 piped water connection is only able to serve in average 60.33% of the total water demand (PAM Jaya, 2015), while the rest of 38.7% is utilizing groundwater, surface water, and rainfall. Groundwater extraction is one of dominant causes of land subsidence in Jakarta (Abidin ; Andreas et al., 2011). So that massive uses of groundwater accelerate land subsidence in some areas in Jakarta and could cause wider expansion of (inland and coastal) flooding areas. (Abidin ; Andreas et al., 2011).

Floods are recurrent problem and become a threat to the citizens of Jakarta every year, both in term of river flooding and coastal flooding. It is noted that in 2002, 2007, 2013, 2014, and 2015, there were major floods that have caused large damage. An overview of these findings is shown in Table 1. The impacts of flooding have increased in recent decades because of a large number of drivers, both physical and socio-economic in nature (Budiyono ; Aerts et al., 2015).

Table 1 Comparison of Jakarta Flood Damage in 2002 and 2007 (Bappenas, 2007)

Description	2002	2007
Precipitation	361.7 mm (mean Jakarta in 10 days)	327 mm (mean Jabodetabek in 6 days)
Inundation area	331 km^2 in Jakarta	454,8 km^2 in Jakarta
Loss of life	80 people	79 people (status of 12 February 2007)
Evacuee	381 people	590,407 people (status of 6 February 2007)
Direct losses	IDR 5.4 trillion (2002 values)	IDR 5.2 trillion (2002 values)
Indirect losses	IDR 4.5 trillion (2002 values)	IDR 3.6 trillion (2002 values)

During this time, 97% of raw water supply in Jakarta come from outside Jakarta, namely from Jatiluhur Dam, Cisadane, and Cikokol River, and only 3% were supplied from inside Jakarta. It is caused by the water quality of rivers and reservoirs in Jakarta which are generally heavily polluted (DKI Jakarta, 2014).

3.2 Model Settings

The integrated model is constructed using Vensim Professional system dynamic software. The time step of the model is set to 0.03125. It seems often enough to calculate the difference and large enough to have a fast running model. The Euler method has been chosen to evaluate the differential equations, for its speed advantage.

The simulation start in the year 2012 due to the data availability. Several variables have used the real data of Jakarta, but the result has been synchronized to the historical planning and water security index of Jakarta. The model simulates a 50-year period, in order to see the plan in short and long term.

3.3 Model Description

Integrated model consists of several sub-models:

1. Population sub-model

2. Piped water sub-model
3. Water consumption sub-model
4. Wastewater sub-model
5. Water-related hazard sub-model
6. Investment sub-model.

Each sub-model is described in detail in the following section. These descriptions provide an overview of each sub-model relation.

3.3.1 Population sub-model

This sub-model calculates the number of people which is influenced by “births” and “deaths” (see Figure 2). It links to piped water consumption sub-model, wastewater sub-model, and water-related hazard sub-model. The population sub-model links to piped water consumption by changing the total number of water demand and also the water used. Total number of water demand is one of the water supply percentage variables which determine the water supply index. It means when the number of people changes, it will indirectly decrease or increase the water supply index.

The population sub-model also links to the wastewater sub-model. Total number of water demand affects the capacity of wastewater treatment capacity, due to the amount of water used, and then changes the treated wastewater. While the number of treated wastewater decreases, it will reduce the river health (and also river health index), and vice versa. Changes of treated wastewater amount will also change percentage of wastewater collected which is one of the variables of wastewater index. On the other hand, the number of people will also affect the percentage of damage due to the water-related hazard.

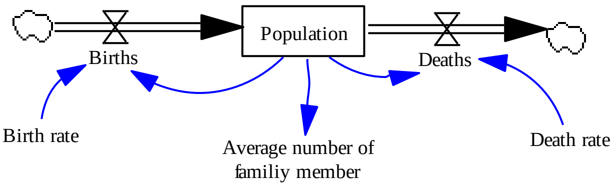

Figure 4 Population sub-model

3.3.2 Piped water sub-model

Piped water sub-model consists of water sources, piped water production, and piped water supply variable. This sub-model relatively simple. There are two types of water sources; internal water source and external water source. The amount of internal water source is very low due to its water quality, so most of the water source comes from outside of the study area. Still the amount of internal water source will be increase in line with the river health improvement.

For the piped water production, it is influenced by the production capacity. Although there is a big amount of raw water, but when the production capacity is not big enough, the production of piped water will be low as much as the production capacity. The amount of actual piped water production may not be the same as the actual water supply to the consumer, due to real loss (lost water caused by the infrastructure condition) and commercial lost (lost water caused by administration issue). The total amount of real and commercial lost is usually called as Non Revenue Water (NRW). The value of NRW will then be used to evaluate the debit of the piped water company.

The piped water sub-model also has a link to water consumption sub-model. The actual piped water supply then will influence the actual piped water used. The amount of actual piped water use, however, may not be the same of the amount of actual piped water supply because the actual used is also influenced by the piped water connection and also water price.

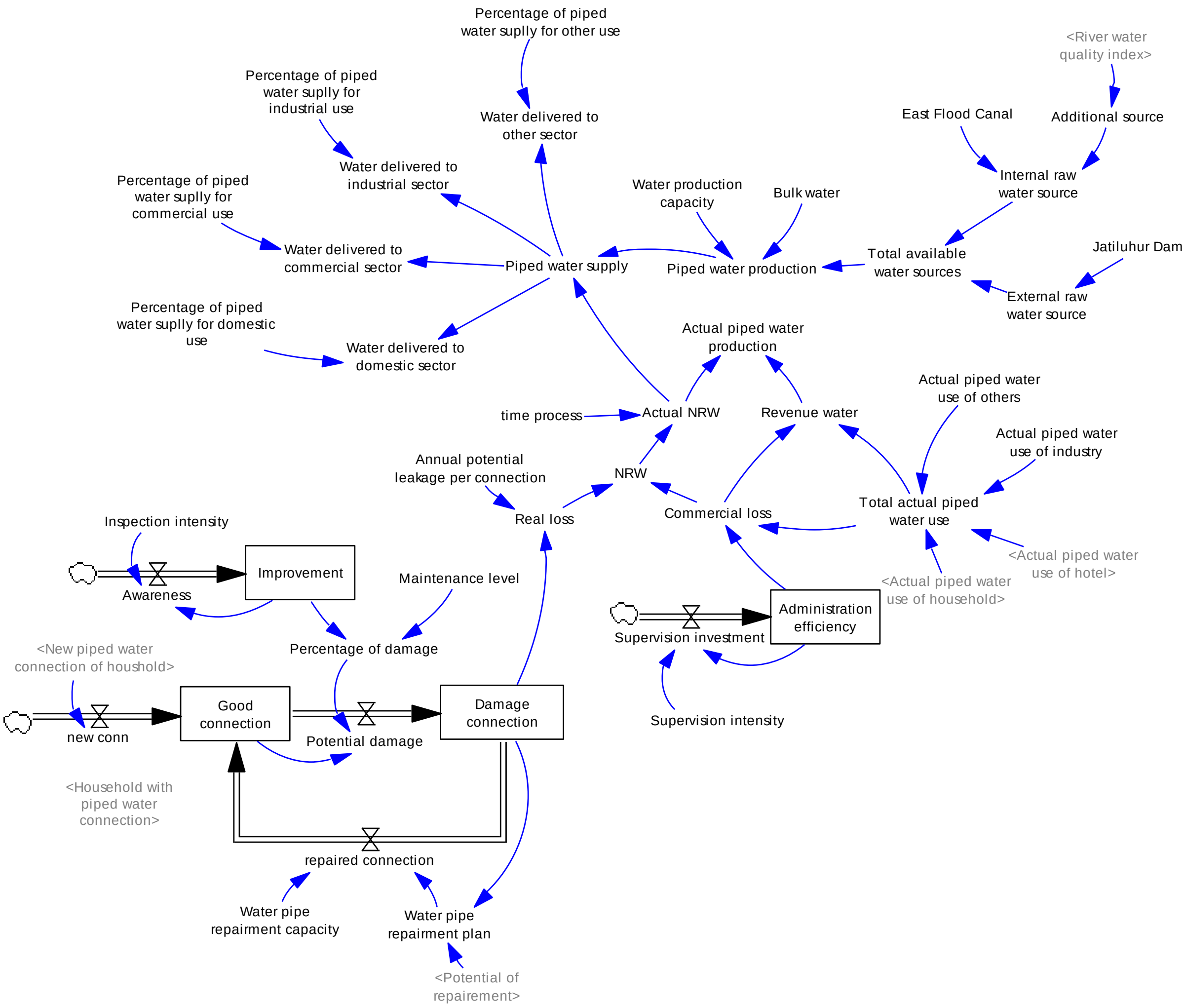

Figure 5 Piped water sub-model

3.3.3 Water consumption sub-model

Water consumption sub-model calculates number of piped water connection based on the investment, and also actual piped water used, both of piped water and groundwater used. As mentioned before, actual piped water used is influenced by actual piped water supply to the costumer, number of piped water connection availability, and also water price. The calculation is done for domestic sector (household), commercial sector (represented by hotels), industrial sector, and others, where each sector has the same calculation systematics.

As an example, households without piped water connection are modelled to use groundwater, while households with piped water connection has choice whether to use piped water or groundwater by considering the water price, the willingness to pay, and groundwater condition.

Based on this rule, the actual piped water used is calculated then linked to the piped water sub-model to calculate the total of actual piped water use, while the actual groundwater used is then linked to the water-related hazard sub-model to calculate the flood damage triggered by the relation of groundwater over-exploitation and land subsidence.

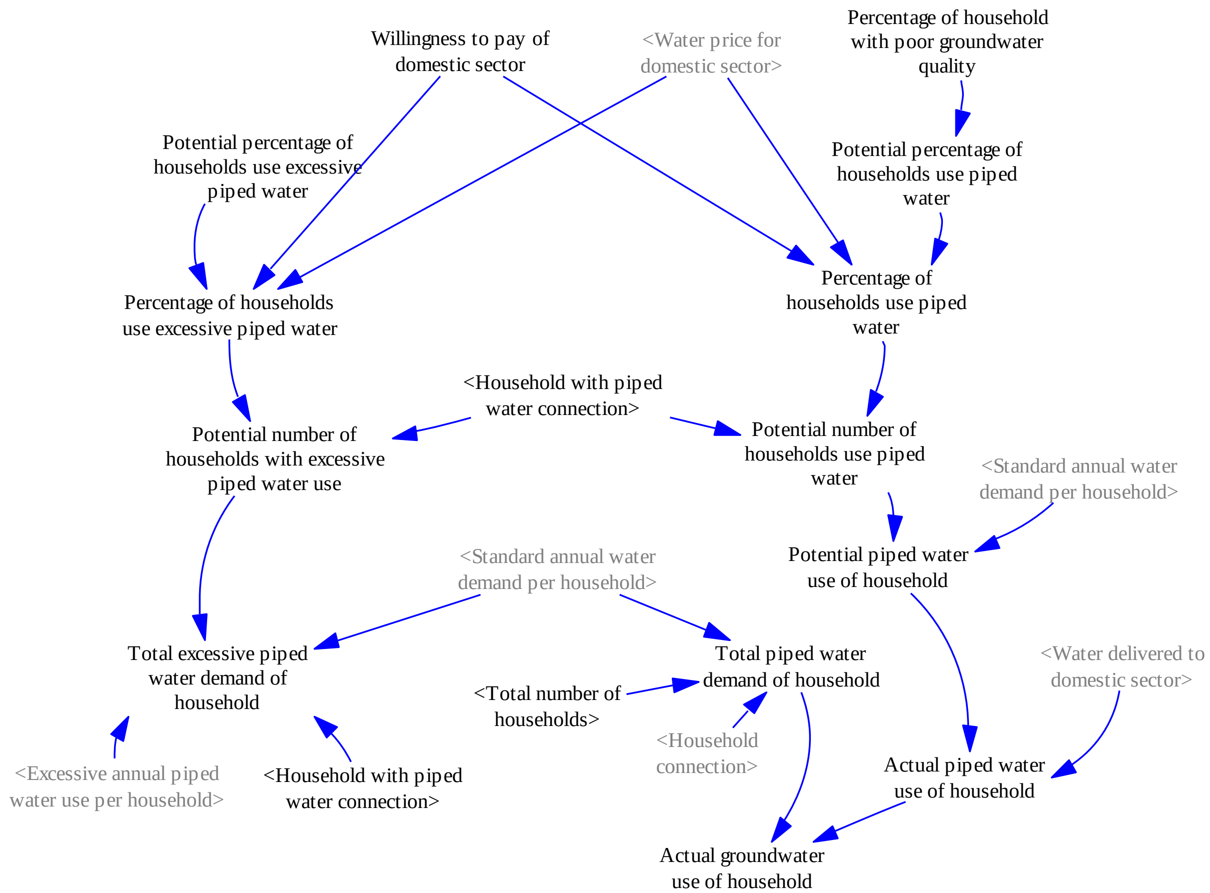

Figure 6 Water consumption sub-model

3.3.4 Wastewater sub-model

Wastewater sub-model calculates number of wastewater connection, amount of wastewater, and also number of treated and untreated water. Wastewater of household without connection to the wastewater treatment plant will go directly to the drainage system and wastewater of household with wastewater connection will go to the wastewater connection plant.

When number of household without wastewater connection is not reduced, it will decrease the river health condition by continuously contaminating the river with the untreated wastewater. When they can be reduced, however, it will not ensure the river quality improvement because it is also depend on the capacity of wastewater treatment plant. While the capacity of wastewater treatment plant is higher, the amount of treated wastewater will also higher. This means the water quality which release to the drainage system is better and can improve the river health, and also vice versa.

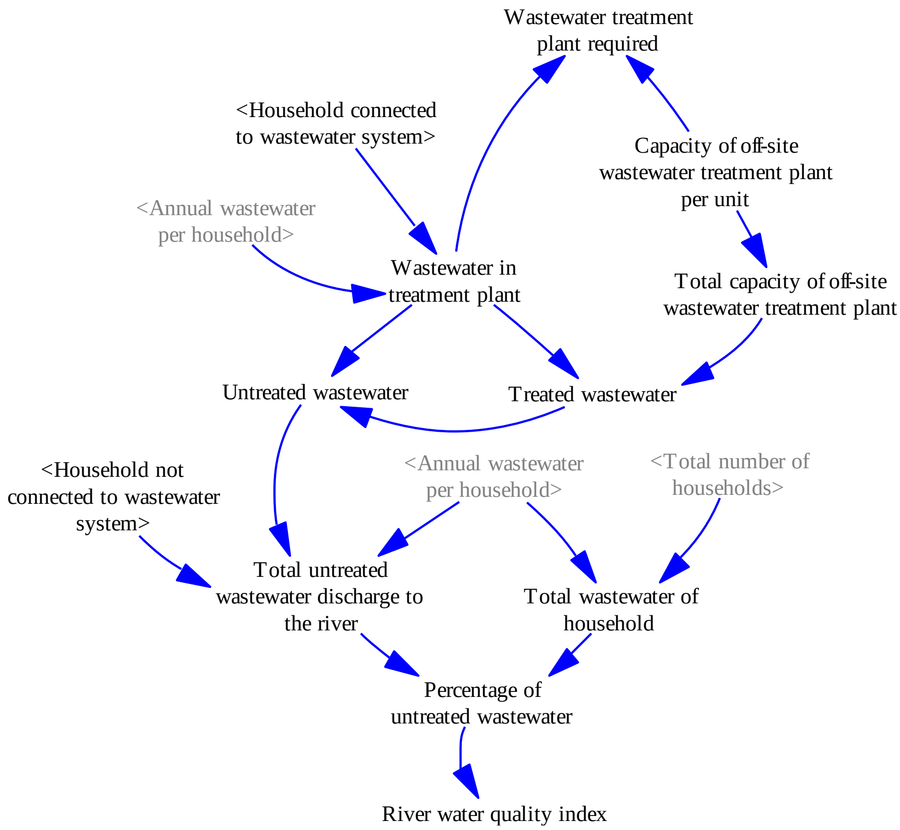

Figure 7 Wastewater sub-model

3.3.5 Water-related hazard sub-model

Water-related hazard sub-model calculates the economic damage due to floods. The economic damage is calculated based on the physical damage due to the flood depth and land use. In this model, the damage factor is getting higher when the groundwater abstraction is also getting higher. This happens because when the groundwater abstraction is getting higher and higher, it will increase the risk of land subsidence that can cause worse floods.

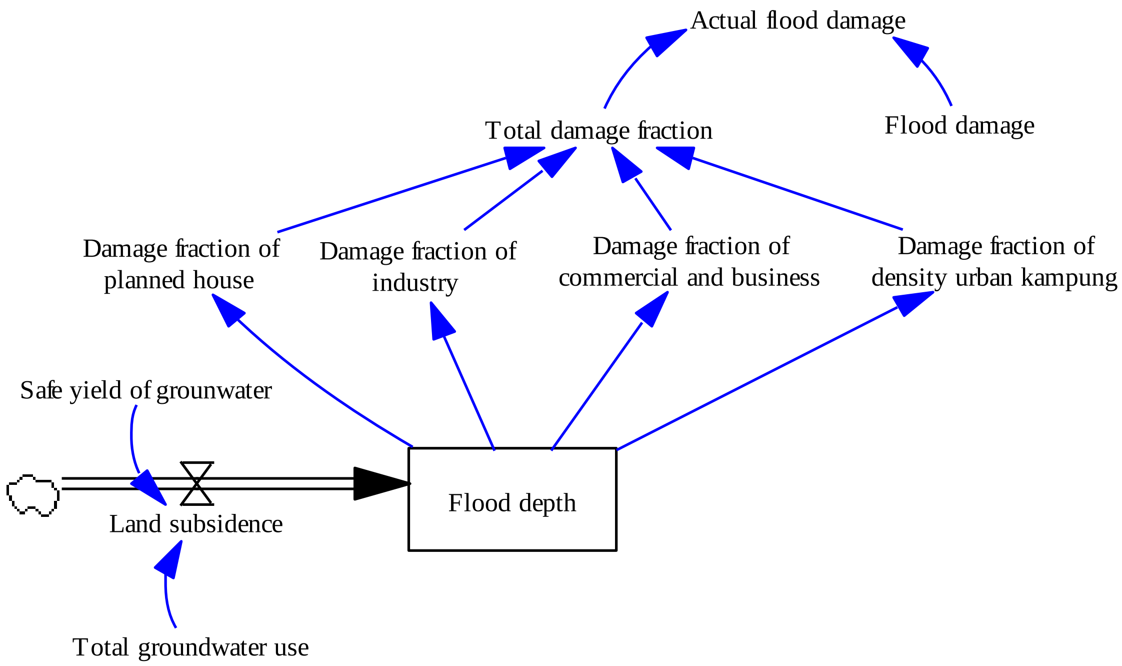

Figure 8 Water-related hazard sub-model

3.3.6 Investment sub-model

The investment sub-model is very simple. It represent the investment of new piped water connection, repairment of piped water connection, and also new wastewater connection and wastewater treatment plan. The source of the investment budget comes from the percentage of investment budet from the water charge and also direct investment, i.e. loan or government assistance. However, the construction of new connection will not only influenced by the amount of the investment but also construction capacity of each works.

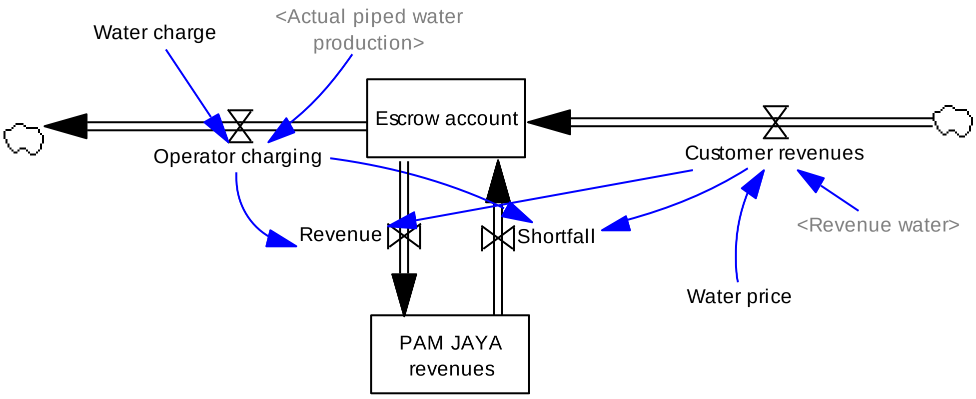

Figure 9 Escow Account Flow

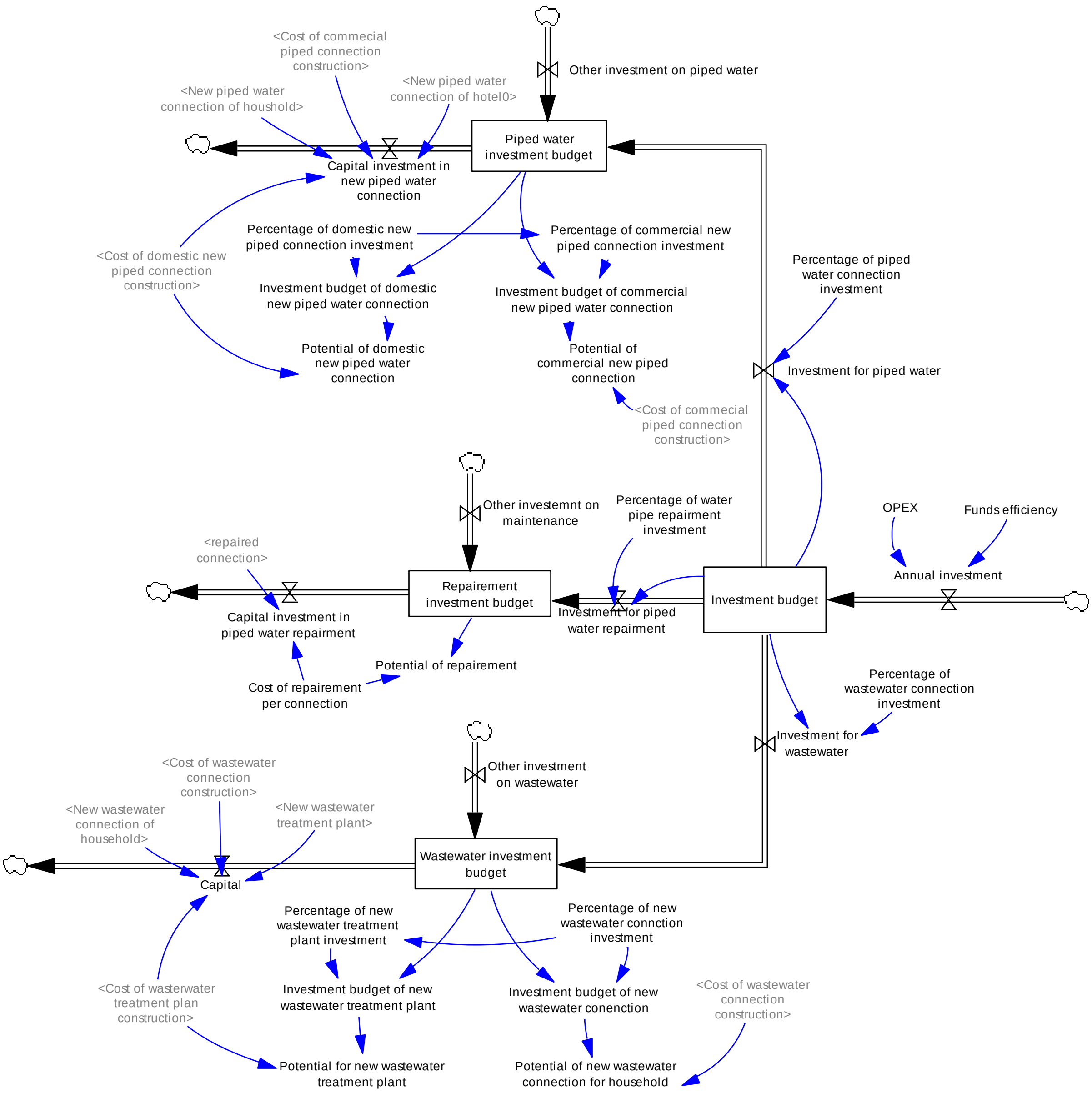

Figure 10 Investment sub-model

3.4 Model Input and Scenarios

The variables that were considered are shown in tabel below. Variables that were considered but excluded due to their complexity include the water quality. Although it is excluded, water quality can be factored in by changing the percentage of connection.

Tabel 1 Model Boundary

Endogenous	Exogenous
Piped water supply	Water resources
Household water demand	Population
Pipe water and wastewater infrastructure	GDP
Transition from not connected household to connected household	Investment

4. Model Calibration and Results

4.1 Model Calibration and Validation

The integrated model was tested through process of "model debugging" to trace and correct errors preventing the model from simulating properly. It was also verified to achieve consistency between model conceptualization and specification. Unit consistency and numerical accuracy of simulation have been checked. Through the model-building process and simulation runs, structural errors have been identified and addressed iteratively.

This model is a simplified model to experiment with preliminary idea and elaborate the method and framework. It used real data of Jakarta for several variables and adjustment number for the rest of them, so for the validation process, the result of this simplified model still cannot be compared to real data. The validation test is done on the next stage of the case study model.

4.2 Results

The result of the integrated model are summarised in this section drawing on model outputs with supplementary explanations provided where necessary.

4.2.1 Baseline Simulation Result

The water balance is represented in the model as piped water production, non revenue water (NRW), and revenue water (RW) component. When the NRW can be controlled, there will be more water to be supplied to the consumer.

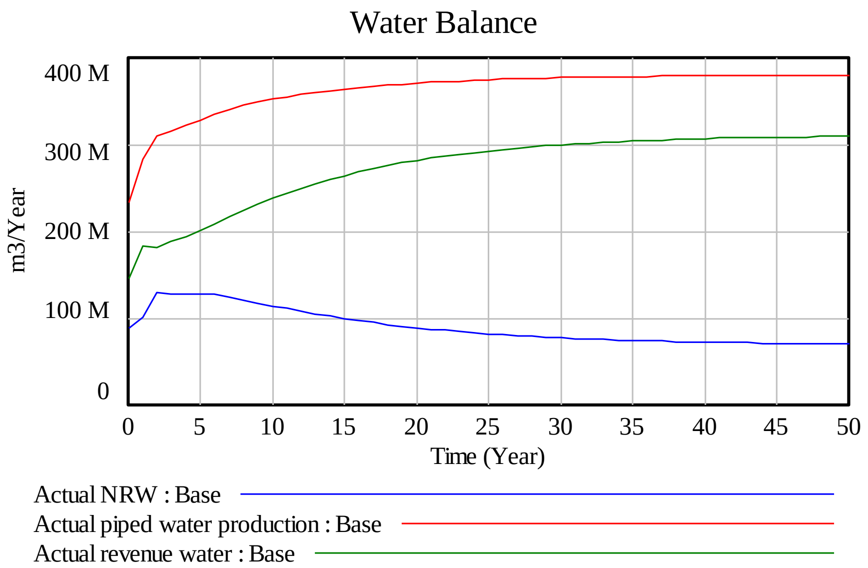

Figure 11 Base – Water Balance

The behaviour of piped water consumption results from the increament in 'water delivered to domestic sector' over this period, as indicated in figure below. The supply starts increasing in year-2 as a result of the infrastructure being repaired to reduce the water loss (real loss-NRW). So also with affordable price, the RW will continue increasing. This reduction of NRW, however, is not sufficient to meet the domestic water demand. This causes the use of groundwater to still increase.

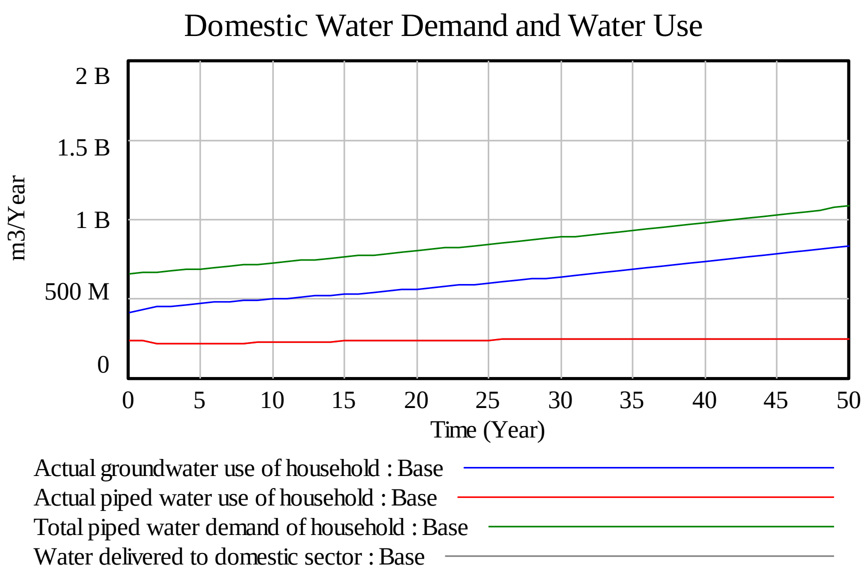

Figure 12 Domestic Water Demand and Water Use

The water supply availability can be increased not only by controlling the value of NRW but also by getting additional water source from the internal system. However the water quality of rivers and reservoirs in Jakarta are generally heavily polluted, so for getting additional water, the river water quality should be maintained by improving the wastewater system. With the current condition of wastewater condition, the figure below shows that the river water quality index is still very low. Water quality index '5' means the water quality is bery bad, while water quality index '1' is very good.

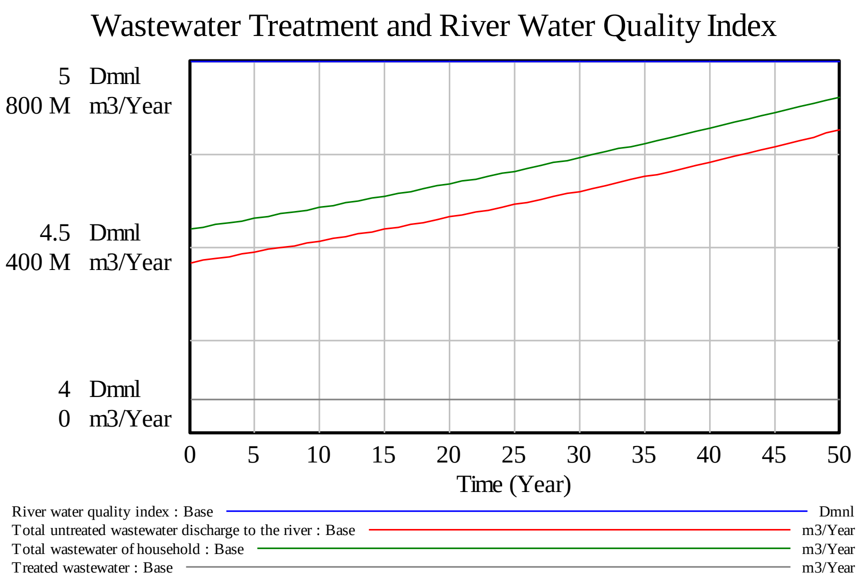

Figure 13 Wastewater Treatment and River Water Quality Index (Water quality index '5' is bery bad, while water quality index '1' is very good)

While water supply can meet the total water demand, the groundwater use will decrease. While the groundwater abstraction is one of the triggers of land subsidence, controlling groundwater use by maintaining the water supply can help to reduce flood damage. With current conditions, while groundwater use keep increasing, the flood damage is also incresing in line with the land subsidence and flood depth.

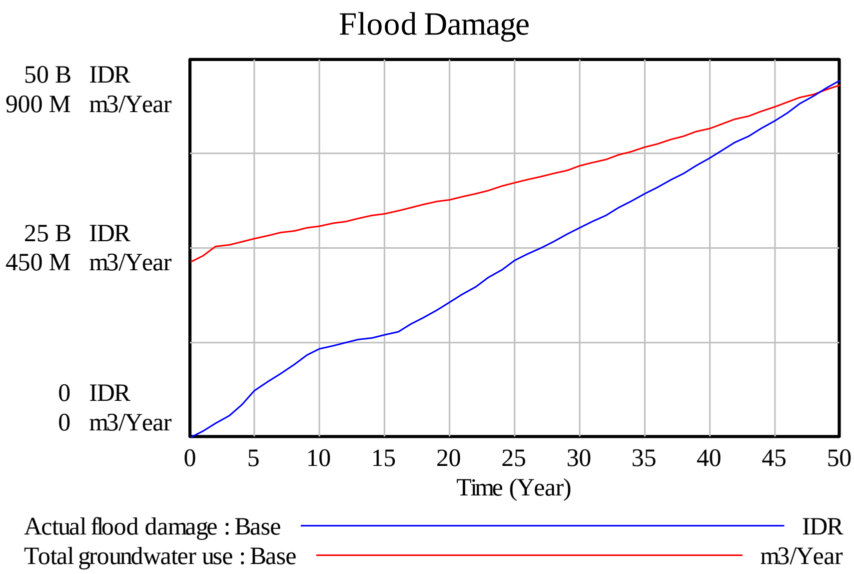

Figure 14 Flood Damage

Base on the baseline situation, the changes of urban water security index is presented in the figure below.

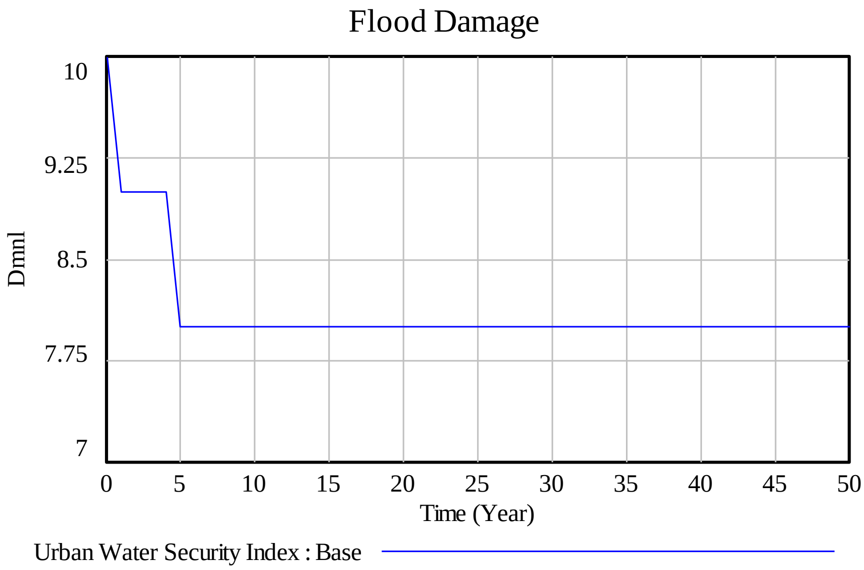

Figure 15 Urban Water Security Index

4.2.2 Scenario 1

For the improvement of the piped water production and connection, wastewater treatment connection and plan, and also flood protection, investment of the infrastructure is absolutely needed. Scenario 1 simulates the situation with the improvement of piped water supply, involves following actions:

1. Control the non revenue water (NRW) condition start in year-5, by:
    a) Increase inspection capacity and regular maintenance to avoid hard repairmen and decrease the real loss due to the damage of piped water connection,
    b) Increase supervision intensity to improve administration efficiency and decrease the commercial loss,
2. Investment in piped water connection repairmen in year-15,
3. Investment in new piped water connection for household in year-20.

The water balance of Scenario 1 which consists of piped water production, non revenue water (NRW), and revenue water (RW) component, is presented in the following figure. Some actions have been made to reduce amount of NRW. In year-5, there is an increament of inspection intensity, maintenance, and also administration efficiency, and also connection repairment. Besides that, there is also additional invetment in connection repairment in year-15. It means there is more water to be supplied to the constumer.

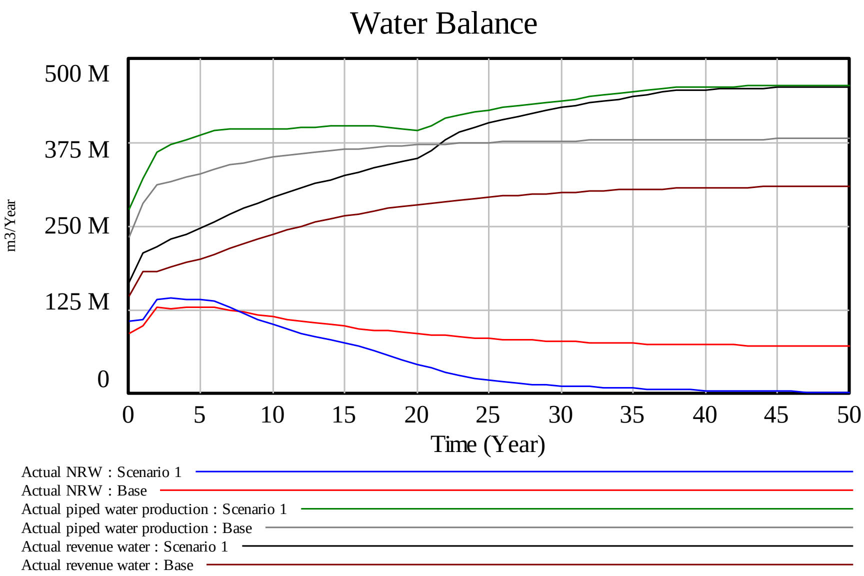

Figure 16 Scenario 1 – Water Balance

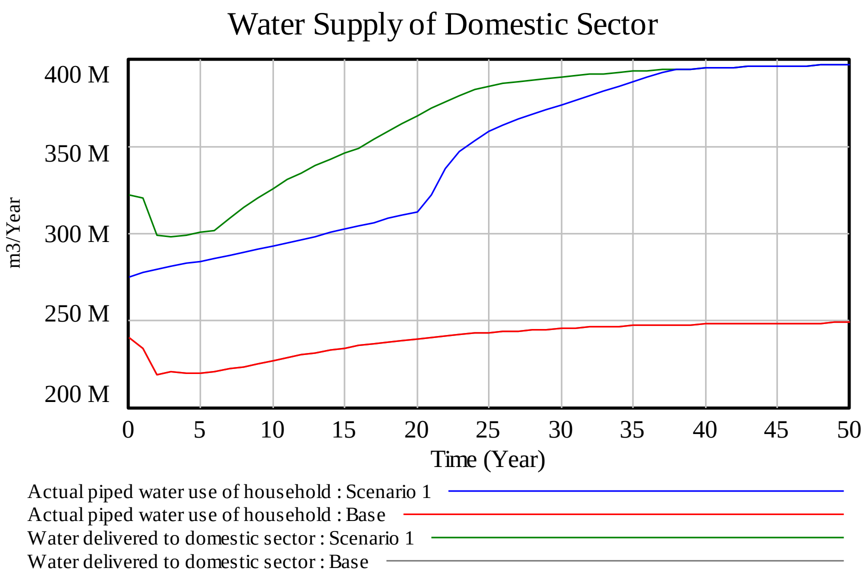

Figure 17 Scenario 1 - Water Supply of Domestic Sector

In year-20, there are construction of new connection of household. The action is done becuase the water supply starts increasing in year-5 and continuously increasing as a result of the reduction of the water loss (real loss-NRW), and there is piped water surplus for the domestic sector. However, this water supply and connection improvement still has not yet met the domestic water demand, which this causes the groundwater still increases.

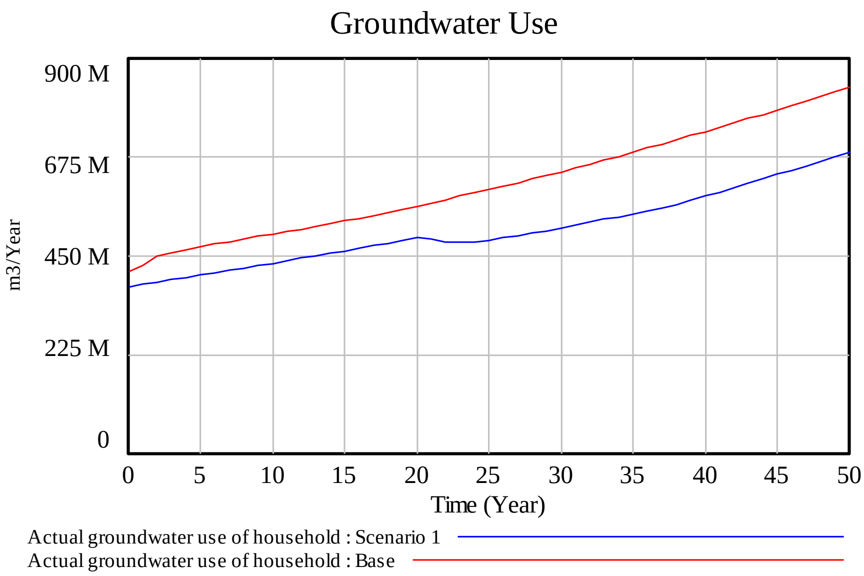

Figure 18 Scenario 1 – Groundwater Use

The actual water supply is still not enough to meet the total water demand, so there is a needed to get additional water sources. However, in Scenario 1, there is no improvement in wastewater system, so the river water still cannot be used as additional water resources. With this condition, the groundwater use keep increasing, the flood damage is also incresing in line with the land subsidence and flood depth.

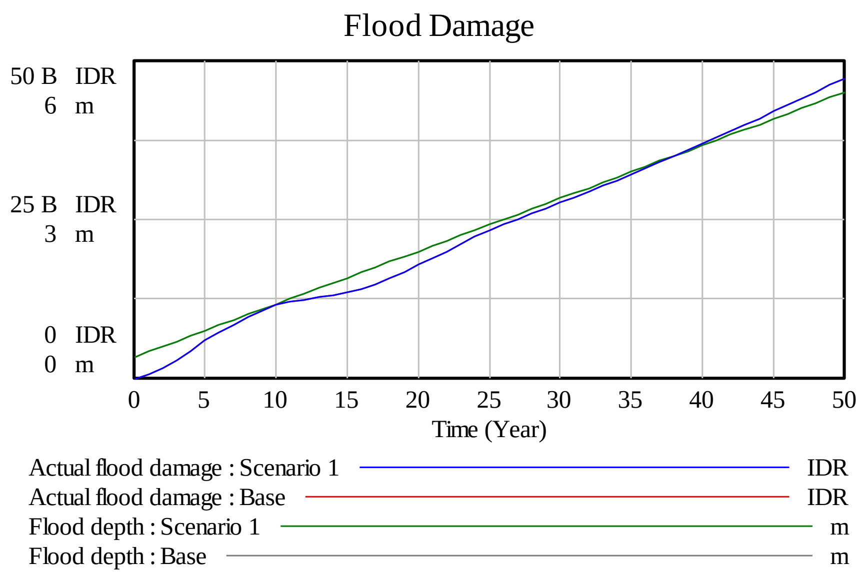

Figure 19 Scenario 1 - Flood Damage

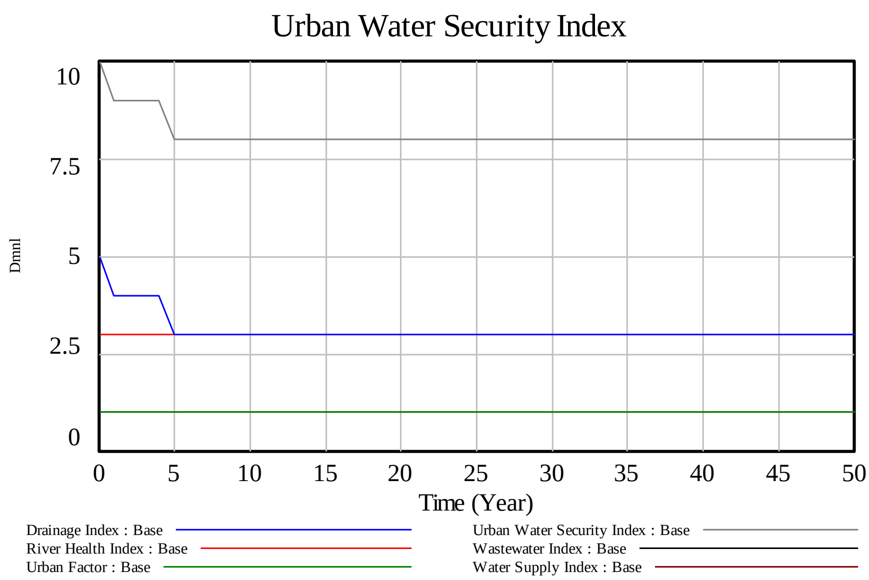

Figure 20 Urban Water Security Index

4.2.3 Scenario 2

Scenario 2 simulates the situation with the improvement of piped water supply and wastewater system, involves following actions:

1. Control the non revenue water (NRW) condition start in year-5, by:

a) Increase inspection capacity and regular maintenance to avoid hard repairmen and decrease the real loss due to the damage of piped water connection,

b) Increase supervision intensity to improve administration efficiency and decrease the commercial loss,

2. Investment in wastewater connection in year-10,
3. Investment in piped water connection repairmen in year-15,
4. Investment in new piped water connection for household in year-20.

The water balance of Scenario 2 which consists of piped water production, non revenue water (NRW), and revenue water (RW) component, is presented in the following figure. Some actions have been made to reduce amount of NRW. In year-5, there is an increament of inspection intensity, maintenance, and also administration efficiency, and also connection repairment. Besides that, there is also additional invetment in connection repairment in year-15. In year-10, there is also an investment of wastewater treatment to improve river water quality for additional water sources. It means there is more water to be supplied to the constumer in year-15 as the result of the connection repairment and improvement of river water quality as the new water sources.

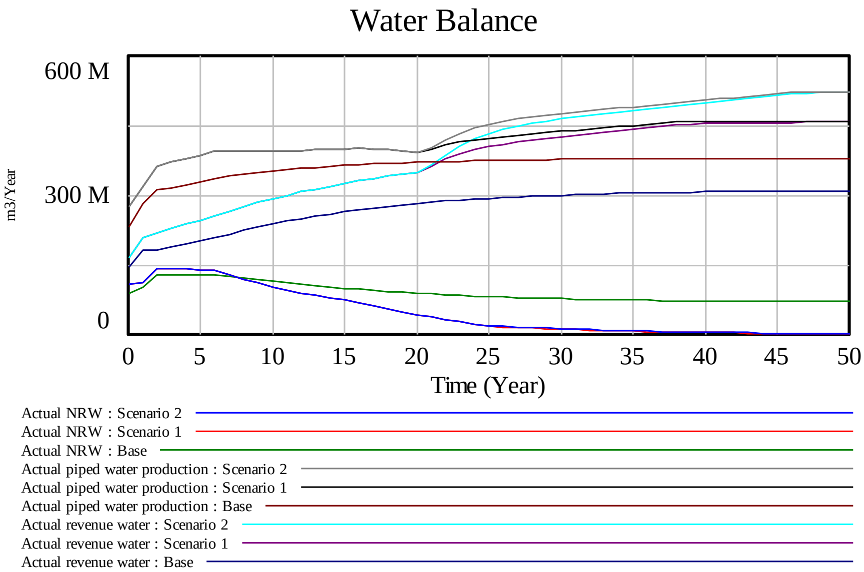

Figure 21 Scenario 2 – Water Balance

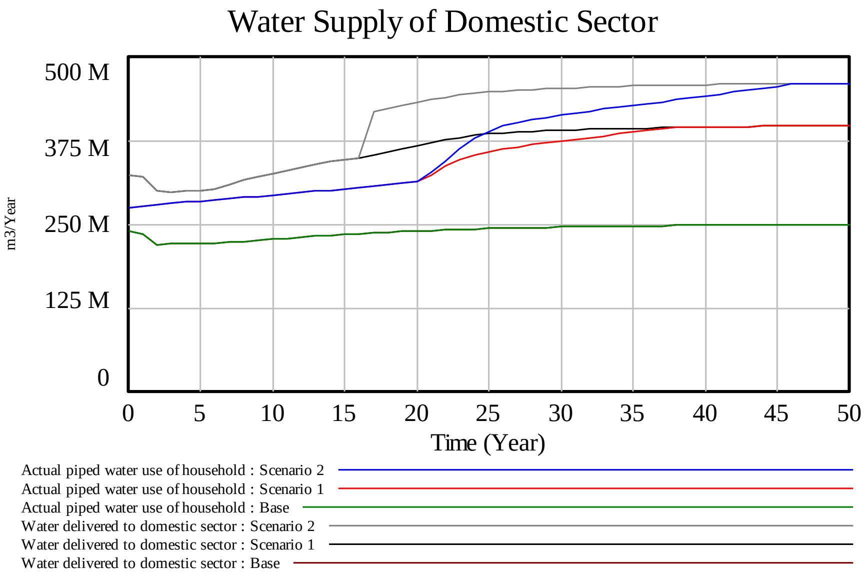

Figure 22 Scenario 2 - Water Supply of Domestic Sector

In year-20, there are construction of new connection of household. The action is done becuase the water supply starts increasing in year-5 and continuously increasing as a result of the reduction of the water loss (real loss-NRW) and the improvement of the river water quality as additional water seources, so there is piped water surplus for the domestic sector. However, this water supply and connection improvement still has not yet met the domestic water demand, which this causes the groundwater still increases.

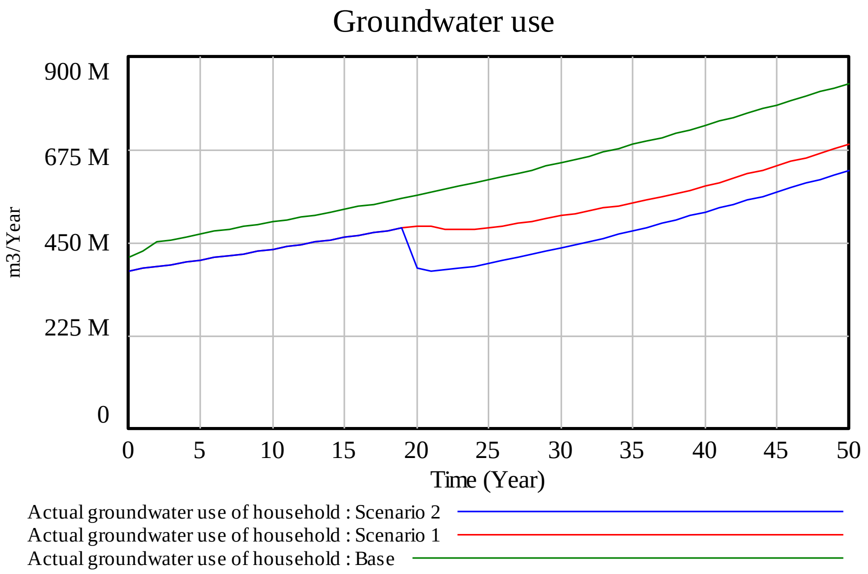

Figure 23 Scenario 2 – Groundwater Use

The actual water supply is still not enough to meet the total water demand, so there is a needed to get additional water sources. With this condition, the groundwater use still keep increasing, so the flood damage is also incresing in line with the land subsidence and flood depth.

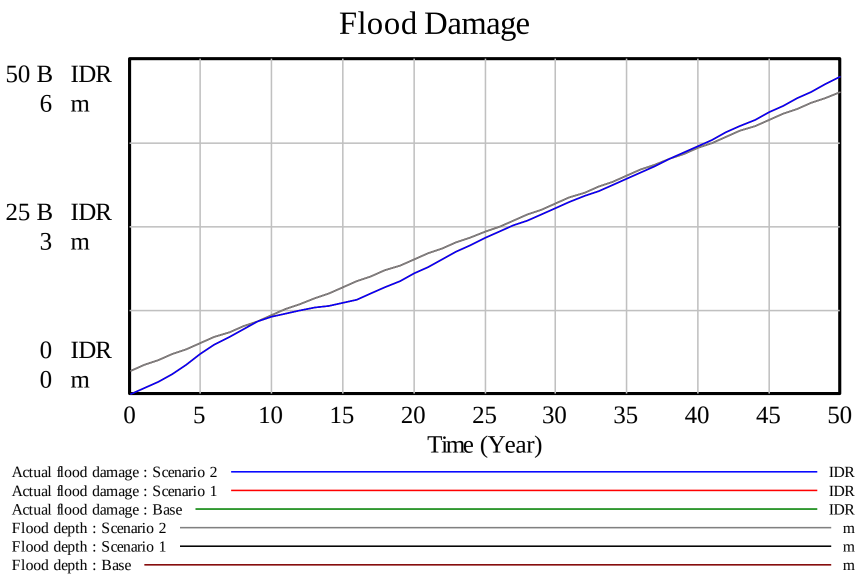

Figure 24 Scenario 2 - Flood Damage

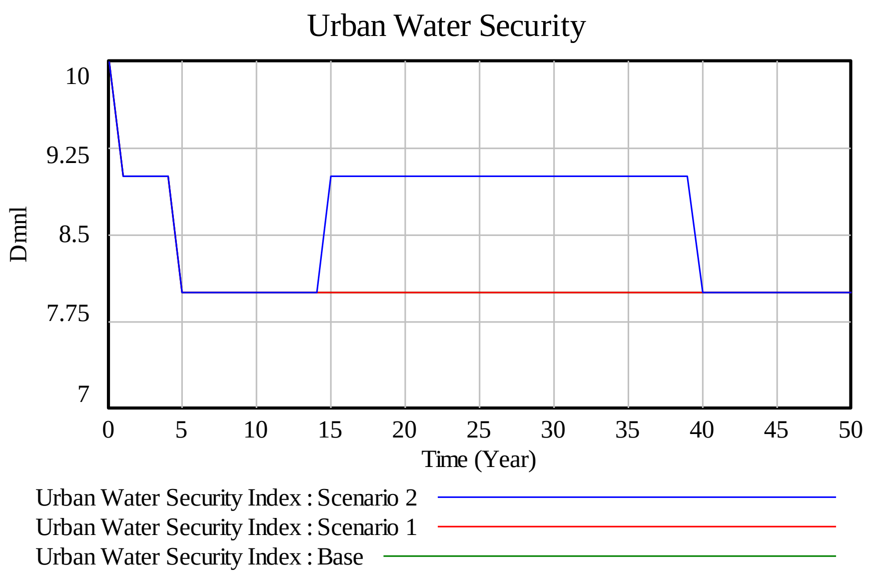

Figure 25 Urban Water Security Index

5. Conclusion

In this paper, a simplified model using system dynamic and several scenarios was outlined, in order to assess the water security index over time due to transient policy action, investment and autonomous responses. The result shows that different policy action and also investment allocation will influence the water security index by changing the availability of water supply, number of piped water connection, repairment of infratsructure, number of wasterwater connection, water quality index, and etc.

We conclude this model is fast and can integrate the water security indicators and urban water system, but is still weak in incorporating sufficient spatial resolution. Still it is promising for Adaptive Urban Water Security Management.

On the next steps, other uncertainties could be added to capture the dynamic of urban water security index; such as water price, willingness to pay, water demand for different categories, etc. Furthermore it is also a challenge to solve the spatial resulution issue. The ideas are to disaggregate the model into several areas with homogeneous characteristic for Jakarta case or couple it with other software of platform.

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