# Reconnaissance study on the need and feasibility to integrate a water distribution model in the DSS of PJT II.

Using RIBASIM

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# FINAL REPORT

UNIVERSITY OF TWENTE.

# PREFACE

This research was done as part of my final bachelor assignment Civil Engineering, at the University of Twente. With this assignment I hope to finalize my bachelor degree, so I can go start my Master program Civil Engineering. This research gave me clear insight on how the work of a civil engineer may look like in the future. I have learnt some important lessons both study and non-study related.

RIBASIM is program that to me has a lot of potential. Working with the basics of the program does not require additional programming skills like many other modeling programs. “What you see is what you get” when using RIBASIM, and that feature provides huge possibilities for implementing RIBASIM at organizations where they have little modeling skills.

I worked at the office of Pusair in Bandung. At the office I spend the most time with Kamelia Octaviani and Ahmad Pribadi, I want to thank them both for showing me around and providing useful tips for a “bulee” in Indonesia. Also I want to thank Meli specially for providing all the “formal” things, especially the quick response when I was at the Indonesian Embassy in The Hague and still some information had to be provided.

I did not carry out this research all by myself, I was fortunate to have supervisors by the likes of Drs. Waluyo Hatmoko, Radhika and Mr. Jan Jaap Brinkman. They helped me with setting-up of the RIBASIM model, and were always available for questions. Also Reni Mayasari and Herry Rachmadyanto of PJT II helped me a lot with questions; I visited them four times for meetings about this assignment, I also want to congratulate them both with their promotion.

My final and special thanks go out to mr. Eelco van Beek, who was my supervisor at Deltares and at the University at the same time. He and Deltares provided me this unique opportunity to carry out my bachelor assignment and at the same time visit the opposite site of the world. I am very fortunate to had Eelco as my supervisor. We will probably meet again in the near future because he is one of the professors who are involved in the master program of Civil Engineering.

This internship provided me a lot of valuable life lesson, which I will cherish for the rest of my life. I had never lived such a different and unique culture like the one in Indonesia. Also this was the first time that I was fully living on my own for a long period of time; I had to meet new people hangout with, and making all decisions by myself, you grow up fast in such circumstances.

# SUMMARY

This research focuses on the water allocation process of PJT II (Jasa Titra 2) in the Citarum river basin, west Java province in Indonesia. The goal of this research was to do a reconnaissance study on the need and feasibility to implement a water distribution model in the DSS (Decision Support System) of PJT II. A water distribution model simulates the water allocation process in an area, based on the demand, availability and policy regarding the water allocation process. Currently there is no water distribution model implemented in PJT II's DSS, and this research focuses on whether RIBASIM (River Basin Simulation Model) could fulfill this role. To answer the research objective, three research questions were formulated. This research gives answer on the questions: which characteristics should such water distribution model consist of, which components should the model contain, and whether the results that the model provides are useful for PJT II. The research was a joint cooperation between staff members of Deltares, Pusair and PJT II.

The program that has been used for this research is RIBASIM; RIBASIM is a hydrological program to analyze the behavior of water balances in rivers under several hydrological conditions. RIBASIM allows policymakers to evaluate water balances due to changes related to the water-infrastructure, -operation and –demand. The input data consists of: hydrological network, water users, water suppliers, operation policies, economic data and scenarios.

The input data for the hydrological network and water-users/suppliers are based on data that currently is being used by PJT II in their water allocation process, and it is attuned to the desired level of detail for PJT II. The structural foundation of the model was based on an existing model that already included parts of the Citarum river basin but did not have the right level of detail. Due to changes to the existing model, a new model was created that was in order with PJT II.

In this research several scenarios were defined to determine the possibilities of this RIBASIM model were. Due to changes on both the supply and demand side, new water balances were simulated. The results of these simulations provide information on where and which effects may occur in these different water balances in the Citarum basin. The information out of these results is useful for PJT II in setting up new strategies or SOP regarding the water allocation process.

This research shows that an implementation of RIBASIM as a water distribution model in a DSS for PJT II is feasible and would help PJT II in their water allocation planning process. RIBASIM would help PJT II setting up new policies about the water distribution in the Citarum basin.

In a further step of a possible implementation, research needs to be done about the upstream part of the Citarum. This research main focus was on the downstream part from Jatiluhur reservoir, the upstream part still needs be defined properly.

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# ABBREVIATIONS / TERMS

| | |
|---|---|
| 6 Cis | Six rivers model in RIBASIM |
| BC-10 | Base case 2010 |
| DSS | Decision support system |
| Ha | Hectares |
| Km. | Kilometer |
| Km2 | Square kilometers |
| M3 | Cubic meter |
| M3/s | Cubic meters per second |
| PJT II | Jasa Tirta II |
| PUSAIR | Indonesian water research institute |
| RIBASIM | River Basin Simulation Model |
| SOP | Standard operation procedure |

# 1. INTRODUCTION

In this section, the background (1.1) and goal of the research is explained. In 1.1.1 the framework of the project is defined, 1.1.2 and 1.1.3 give information about the organizations and areas involved. The definition of the problem (1.2) can be made out of the background (1.1), the problem is defined in research objectives and questions (1.3). 1.4 & 1.5 provide information about the approach and structure of the research.

## 1.1. BACKGROUND

### 1.1.1. PROJECT FRAMEWORK

This research has been collaboration between three organizations: Deltares, Pusair and Jasa Tirta II. Deltares was the initiator of the research in cooperation with PJT II for which it is for, Pusair supported the research.

Deltares is a Dutch independent research institute that is specialized in water management, hydrology, infrastructure and soil mechanics. It is one of the premier research institutes in the world, which innovations and technologies are implemented on several sites over the world. Its slogan is “enabling delta life” which means enabling living in delta areas. Deltares works close with many governments in creating solutions and policies to make provide safety for the combination of urban and delta area (Deltares.nl, 2012).

Deltares is part of a joint cooperation program (JCP) together with Pusair, KNMI (Royal Dutch Meteorological Institute) and BMKG (Indonesian body of meteorology, climatology, and geophysics). The program was started in 2011 and runs till 2015, its objectives are: “Knowledge sharing and capacity building between Indonesian and Netherlands Research and Development Institutes in the field of water resources and climate” (Views Magazine, 2010)

Pusair is a abbreviation for “Kementerian Pekerjaan Umum Badan Penelitian Dan Pengembangan Puslitbang Sumber Daya Air”, translated to English it means “Ministry of Public Works Research and Development Center for Water Resources”. Pusair is the water resources department of the ministry of public works of Indonesia. In contrast to Deltares, Pusair is not independent but a public institution. Pusair does not directly manage any delta, but provides institution that does with advice and expertise about water-related topics.

The goal of this research is to provide PJT II first insights on the possible implementation of RIBASIM. This goal can be divided into multiple goals, which eventually will lead to those insights:

- Build a model of the Citarum river basin using RIBASIM
- Carry out simulations to show the possibilities/capabilities of RIBASIM
- Provide recommendations for possible further implementation of RIBASIM within the modeling framework of PJT II.

The study area is the Citarum river basin, which falls under the jurisdiction of PJT II, more information about this can be found in the next sections. (1.1.2, 1.1.3)

### 1.1.2. PJT II

PJT II (Jasa Tirta II) is a public organization that is originally founded in 1970 under the name of “Jatiluhur Authority Public Corporation” by the Indonesian government. In 1999 the name was changed to the current one Jasa Tirta II public corporation. PJT II is been assigned to manage the complete Citarum river basin, and parts of the Ciliwung and Cisadane river basins. This starts from the watershed areas till the channels mount to sea. The work area of PJT II covers 72 rivers and tributaries, which are viewed as one hydrological network; in total the area of the basin covers 12.000 km2. PJT II main concern is to manage the water resources allocation process at Jatiluhur reservoir properly. Many areas are dependable on the water of Jatiluhur, the drink water supply for Jakarta is the most premier one.

In Figure 1 the total total work area of PJT II is shown. It starts south of Bandung and ends north bordering the Java Sea. The map shows the (hydrological-) infrastructure in the work area. This research focuses on the northern part; this area is the Citarum river basin. More about the Citarum river basin will be explained in the next section.

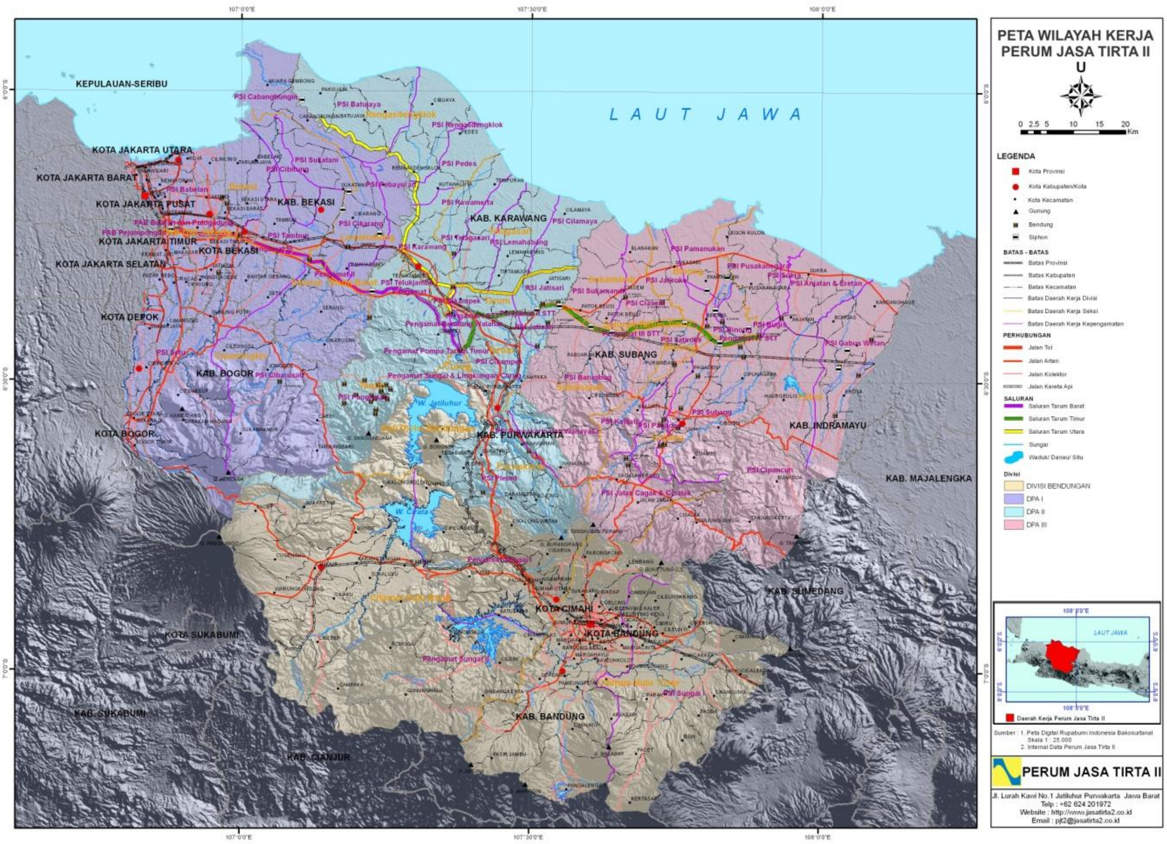



FIGURE 1: WORK AREA PJT II

### 1.1.3. CITARUM RIVER BASIN

The Citarum is a river basin that is located in the West Java province of Indonesia. The Citarum is one of the 6 Ci’s(Rivers) in western Java(Banten, DKI Jakarta and West Java), it is also the biggest one of the six(270 km.). The origin of the Citarum is on Mount Wayang near Bandung, from this point the river floats in Northern direction to the Java Sea. Along the river the government built three water basins: Saguling, Cirata and Jatiluhur. The combined effective volume of the three Citarum cascade reservoirs is about 3.276*10^6 m3. The first two cascade reservoirs (Saguling and Cirata) are managed by the electrical company: PLT (Dijkman J.; Krogt W.v.d. ; Hendarti; Brinkman JJ, 2012). The third (Jatiluhur) reservoir is managed by PTJ II, unlike the first two this reservoir is intended for multiple purposes, not only electricity but also domestic and irrigation water.

The Citarum is the main domestic water supplier for the Jakarta area; approximately more than 14 million people are relying on water out of the Citarum basin, and because of the rapid growth of Jakarta it is expected to be more in the near future. To make sure that the water allocation is done properly, the following priority list is set up (Djajadiredja, 2011):

1. Domestic
2. Agriculture
3. Industry
4. Energy

The total potential water availability of the Citarum river basin is annually 12.95 billion m3. Approximately the Citarum provides 6.0 billion m3 and the other rivers contribute 6.95 billion m3 to the basin. The existing hydrological infrastructure can control about 7.65 billion m3, the rest of the water will flow unregulated. In Figure 2 the distribution of the water resources are illustrated. (Idrus H.; Mardiyono A.; Andrijanto)

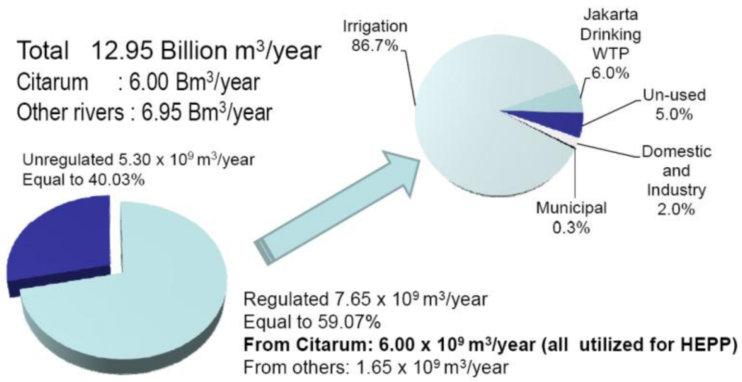



FIGURE 2: CITARUM RIVER BASIN DETAILS

As seen in Figure 2 Irrigation is the main user of water (86,7%) followed by domestic(6%), Industries(2%), municipality(0,3%) and approximately 5% will be unused. It is expected that the river basin will only able to cope with the demand up to year 2015. After 2015 in the current situation the demand will be expected to be higher than the supply. In Table 1 some facts about the Citarum are shown, these facts show the magnitude of the area and the urgency for proper management.

TABLE 1: CITARUM CHARACTERISTICS

| | |
|---|---|
| Total Area | 12.000km2 |
| Population along the basin | 10 Million (50% Urban) |
| Number of served population | 25 Million |
| Hydropower Capture | 1400 Mega Watt |
| Irrigation Area | 240.000 Hectare |

## 1.2. PROBLEM DEFINITION

In the current situation PJT II has a DSS (Decision support system) of the river delta. This system is designed to support decision makers in their policymaking for the Citarum river basin. In the DSS there is a module that continuously makes analyses of the data that enter the system, these analyses then will be evaluated using rules and regulations. The analyze module is built out of different hydrological models; examples are Rainfall-Runoff and water allocation models. In Figure 3 a schematic overview of the DSS is shown.

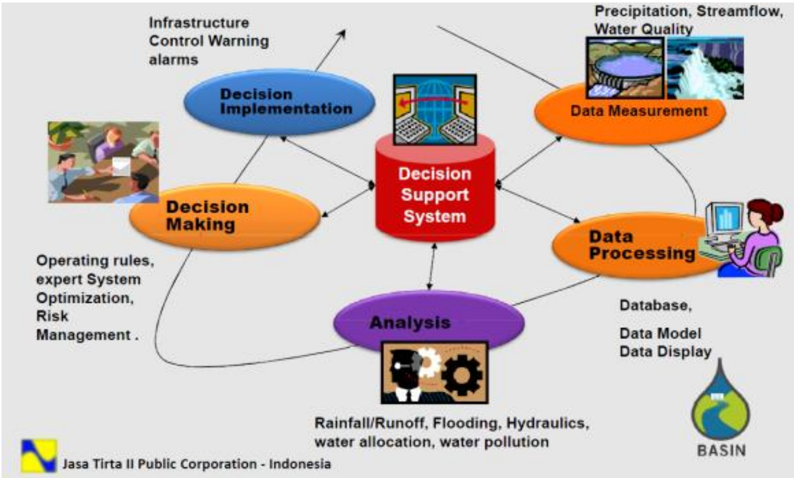



FIGURE 3: SCHEMATIZATION OF DSS

At this moment the models are built in Excel. Although Excel is a good program, there are more advanced software packages available. Therefore, the goal of this research is to do a first research about the possibility to implement the software package RIBASIM into the DSS of PJT II. RIBASIM (River Basin Simulation Model) is a software package that has been developed by Deltares. RIBASIM is designed to evaluate different measurements/conditions in a river basin, and the effects that those events have in relation to the water balance. Basically RIBASIM is a water balance simulation of a river basin, features like water demand and supply are the main components. Implementing RIBASIM would help PJT II for their policy making in relation to water allocation, because it is expected that the water demand will be higher than the supply in the near future, so good policy is keen to maintain a healthy river basin.

Deltares modeled all the six rivers in West Java in RIBASIM; this model is called the “6Ci’s”. The Citarum river basin is one of those six included in this model. For this research the 6Ci’s model will be used, with the primary focus on the parts that are within the jurisdiction of PJT II.

## 1.3. RESEARCH OBJECTIVES & QUESTIONS

The main goal of this research is to carry out a reconnaissance study on the need and feasibility to integrate a water distribution model in the DSS of PJT II.

In this study the main focus will be on identifying the current situation and searching for differences with the possible “future” situation. Recommendations and conclusions will be made out of the results, mostly based on quantified results.

The research will be conducted by answering the following main research questions:

1) What are the characteristics of a water distribution model as needed for PJT II?
2) Which components should such water distribution for PJT II contain?
3) Are the kind of results produce by such water distribution model realistic and useful for PJT II?

## 1.4. RESEARCH APPROACH

At first, the current situation/model needs be studied. This will be done using existing documentation and models. By studying the old situation (PJT II DSS), it will be possible to find differences with the new one (RIBASIM). Also analyses need to be made on how the current water demand is determined.

Next the requirement list for the RIBASIM application will be set up. This will be done using intensive meetings with shareholders/specialists of PJT II. In this phase it needs to become clear which level of detail is the right fit for purpose.

After setting up the requirement list, the RIBASIM application will be analyzed in this phase, the functionalities and possibilities of the application will studied. The comparisons will be made between the possibilities of RIBASIM and the requirements that are set up. Therefore the functionality of RIBASIM for this case study can be defined.

In phase four, phase- two and -three are being put together. In this phase the model is being built using the data gathered in previous phases. The restrictions and possibilities that the previous phases provided are taken into account. Several scenarios are being created to show the possibilities that RIBASIM has.

At last, the finalization of the report will be carried out. During the overall process there will be continuously work on the documentation part, in this phase all the documentation will be combined into one final report. In the final report, recommendations will be done about further steps regarding this subject.

## 1.5. RESEARCH STRUCTURE

First the RIBASIM program is being explained in section 2, on how it operates and is set up.

In section 3 the methodology that is being used is discussed. It starts with explaining the current method to determine the water demand by PJT II. The RIBASIM program is explained in section 2 but the input data that is been used for creating the model in RIBASIM is explained and defined in section 3.

In section 4, the results of the model are shown. This research focuses on the outlook of the model and the simulations it could do. The actual numbers that the simulations provide are not that important, the focus is on how the model operates when characteristics of the scenarios are changed. A base case and four scenarios are created to simulate these changes.

In section 5 and 6, the outcome of this research will be discussed and conclusions will be made upon the results and methodology that was being gathered and used.

The research ends with the references and appendixes that are referred to in the report.

# 2. RIBASIM

## 2.1. PROGRAM DESCRIPTION

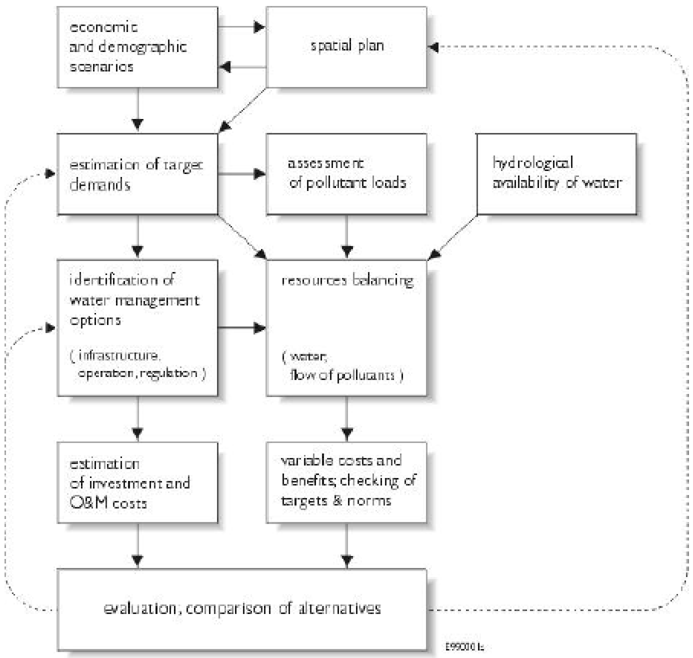
In this section the program that will be used to design and create the model will be explained. This program is being called RIBASIM (RIver BAsin SIMulation), different topics about the capabilities and usability of this program will be brought forward. This chapter is based on (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008).

### 2.1.1. WHAT CAN RIBASIM DO?

RIBASIM is a specially designed tool to support policymakers in their decisions regarding water allocation. River basins are usually complex and contain multiple points and areas that need or supply water from and to the system. In RIBASIM a schematization of the hydrological infrastructure is been made using links and nodes section 3.2. Each link and node presents a specific hydrological feature in the area; each feature has its own characteristics. Basically RIBASIM simulates all the relations that these features have regarding the need or supply of water. Changing the characteristics of the features or the relations between them, different water balances will occur. By evaluating these different water balances conclusions and recommendations are being taken, these recommendations are to support the policymakers.

Figure 4 presents the major components and inter-relationships in the planning for a river basin. This figure shows the process of balancing resources in water resources management. From top to bottom situations and scenarios are created, after that estimations of the target demands are been made. These estimations and options of water management lead to the balancing of resources. The balance that has been created will have certain consequences; these consequences can be expressed financially. Evaluating the several consequences and alternatives can lead to new plans for resources management. The role of RIBASIM in this process can be the overall simulation of it

FIGURE 4: COMPONENTS RIVER RESOURCES PLANNING



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### 2.1.2. WHAT IS THE RIBASIM INPUT

To use RIBASIM several input variables need to be defined. These inputs range from scenario's till water infrastructure till the demand and supply of water. There are five sections that distinguish the multiple inputs, except for the economic data each of the inputs have to be covered to generate a working model. The economic data is an optional input that can be used to analyze the monetary consequences of allocations. The input for RIBASIM is according to (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008):

1. System
    a. Infrastructural network
    b. Policy
    c. Demographic Content
2. Water demand
    a. Demographic
    b. (Economic)
    c. (Crop water requirements)
    d. Current and future water demands
    e. (Pollution generation)
3. Water Supply
    a. Historical inflows
    b. (Groundwater resources)
4. (Economic Data)
    a. Water use rates
    b. Capital costs
    c. Discount rate estimates
5. Scenarios

The RIBASIM model requires three main inputs variables to do a water allocation simulation. First of all there needs to be a hydrological infrastructure built out of nodes and links. For this research the hydrological network of the 6Ci's will be used. Second there needs to be water supply in the area, surface runoff and groundwater flows are three examples of those inputs. Third and last there is a water demand side, this side consists all the different water usages like domestic and agricultural. When each of these three inputs are included, the model is ready to run simulations. Other inputs are economic data to express water shortage in monetary damages, and scenarios were different policies are used for the water allocation. Every run of the model is basically running a scenario; by changing the properties of the model different scenarios are generated. This may vary from climate change to infrastructural modifications to new policies regarding the standard operation rules. Every change to the model will likely generate a different outcome of the allocation, therefore organized working is essential.

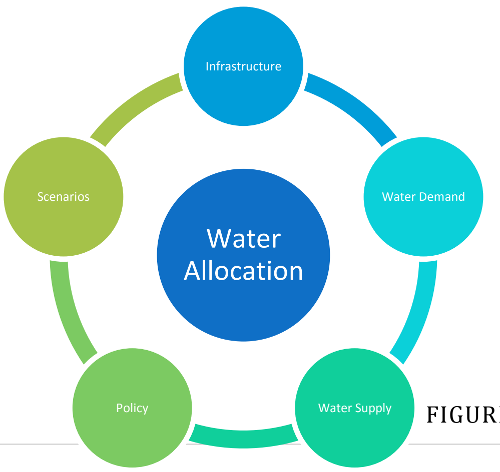


FIGURE 5: WATER ALLOCATION INPUT DATA

### 2.1.3. HOW DOES RIBASIM WORK?

RIBASIM calculates the water balance in a system for each time-step, when all the time-steps are been proceed the simulation is completed. A time-step may vary from months to a couple of days. The amount of time-steps in this study is similar to the one used by PJT II in their water demand schedule: 24 time-steps for each year by dividing each month in two. In each time-step RIBASIM simulates the water balance based on the water- supply, -demand, policy and scenario which are applicable in that time-step. Input variables may vary over time, therefor it is important that all inputs are applicable on the same time-step unit; otherwise inconsistencies could occur caused by overlapping inputs.

The time-step that is being used in this research is larger than the time it costs for water to travel from the most upstream point to most downstream point, assuming there are no restrictions. Therefore relatively simple mass balance equations are been used (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008). In these equations the inflow of a site equals to the outflow of it during the same time-step. Therefore, no residual water can be found in streams and non-storage sections of the river basin. In reality this is not the case but it is adequate for the goal of this research. The actual time-steps that are been used can be seen in in appendix E.

For simulating a water balance, two features have to be at least being included: 1 an hydrologic period that varies over multiple years, 2 a demand series for one year. In Figure 6, a representation is displayed; this figure shows the relation between the supply- and demand-side over time during a simulation.

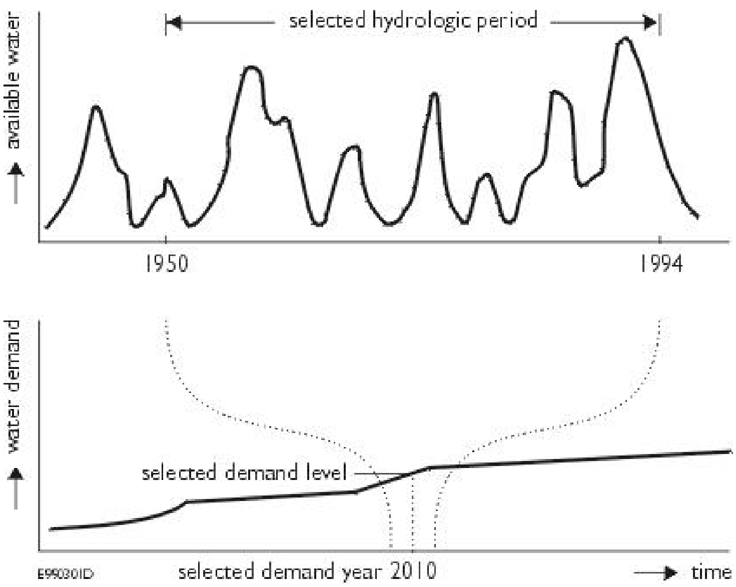


FIGURE 6: RELATION DEMAND VS. SUPPLY

Each node that represents a demand of water, has an own specific source list. This source list includes all the sources that can be used to fulfill the demand of water (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008). In the default situation an automatic source list is been made by RIBASIM, this list includes all the possible sources for water no distinguishes are been made between the different sources. But it also possible to create modifications to the source list, this will generate a “source priority list”, the node then will try to gather water following the priority list that is stated. In the design that is made in section 3.2, no modifications are been made to the source priority list.

The process of simulation works in time-steps, each time step RIBASIM creates a water allocation that is done priority after priority (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008). Each simulation step consists out of two phases: targeting phase and the allocating phase. In Figure 7 a schematization of the allocation process for each priority is displayed. The horizontal line represents the borders of each time-step.

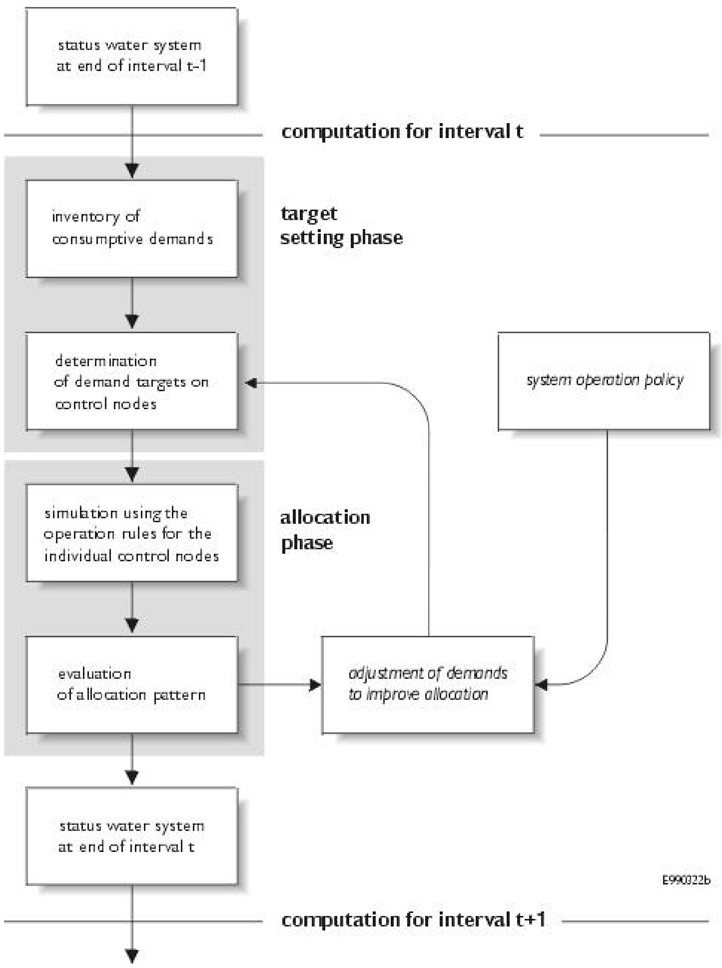

FIGURE 7: WORKING OF RIBASIM

The status of the water system in time-step t-1 is the starting point for the computation. In the target setting phase, RIBASIM first identifies the demands that will be consumed. At the end of the first step RIBASIM knows what the demand is in the network. After determining the demand RIBASIM identifies the water that is available for each source node. The water can be available from different sources: fixed/variable inflow nodes, return flows of irrigation areas and public water supply, reservoirs and more. The most complex and important water supplier for this study is the behavior of cascade reservoirs towards water demands.

In reality reservoirs have standard operation rules, which are used as guidelines for reservoir management. One of the benefits of RIBASIM is that it can actually simulate SOP. If there is no discharge restriction defined, then the outflow of the reservoir in RIBASIM will be equal to the demand, provided that the inflow or current volume is sufficient (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008). Due to the SOP this is usually not the case, and therefore RIBASIM will determine what the discharge will be.

In the second phase the allocation phase, water is being routed through the network in a downstream direction. Each demand node is initially given a priority; the demand nodes with the highest priority (1) will have the water allocated first. After priority 1 RIBASIM allocates water to priority 2 etcetera. With this method the demand nodes with the lowest priorities will the first ones to deal with water shortage, this depends on the network. A high priority will not immediately mean no shortages before all the lower ones have, it depends highly on the network and how much RIBASIM can “control” the allocation.

RIBASIM does not make distinguishes between demand nodes in the same priority category. RIBASIM works following the “first come, first serve” idea, this means that the first demand nodes downstream are the first ones to acquire water. This will lead to water shortages to be likely downstream (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008).

The results are expressed in terms of water shortages, evaluations and adjustments are being made on the results of shortages. Changing settings in the target phase could lead to different results. In section 4, the results of the simulations are shown and explained.

#### 2.1.4. MODEL SCHEMATIZATION

In the RIBASIM application the Citarum river basin is implicated using a schematization. This schematization consists out of all the major water extraction and supply points, also the points where water gets distributed or allocated are included. For such schematization it is impossible to include all the small and different water users. Therefore, a clear distinguish had to be made between the relative important regional basins and the small local basins. For this research there is only focus on the regional basins, with a higher level of detail more and more sub-basins could be included. This is something that requires more study, but it remains questionable if the addition of more small basins would give a more accurate analysis of such a large basin like the Citarum.

An illustration on how the process of schematization works is pictured in Figure 8. The left side illustrates the initial situation how it is in the reality, and the right side shows the schematization in RIBASIM of the same situation. What stands out is that the location depends on the relation with other features instead of the positioning on the map. The main thing that RIBASIM does is simulating what all the different relations regarding water allocation do. So RIBASIM is not necessarily a complete hydrological simulation of the whole area, but only focusing on the water allocation relations.

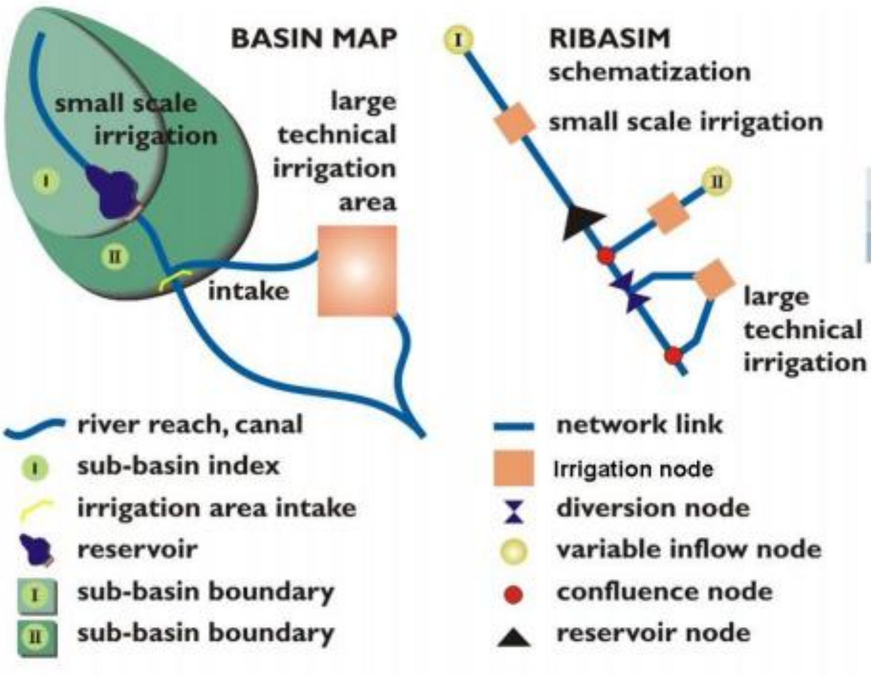


FIGURE 8: RIBASIM SCHEMATIZATION

**Nodes and Links**

The schematization is carried out using nodes and links that represent certain features in the area. Each node and link has its own characteristics that are based on the features in the basin. The schematization is a conversion from “reality” to a virtual simulation. The network of nodes and links consists out of all the features that could have influence on the water balance in the area. There are four clear distinguishes between those features:

1) Water infrastructure, these are the water flows that transport water. (Surface and groundwater reservoirs, lakes, rivers, canals, pipelines.)
2) Water Demand, these are the water users. (Domestic, agricultural, industries, hydropower)
3) Water Supply (Water flows, evaporation, precipitation, runoff, groundwater flows.)
4) Water management (Reservoir operation rules, water allocation rules)

Each of these above mentioned features has its own specific node or link type in RIBASIM. And by connecting all these different types a network that has the same features like the reality will be created. An overview of all the different nodes and links is showed in Figure 9. More details about the functions of these nodes and links that are used are stated in section 3.3.


FIGURE 9: NODES AND LINKS

# 3. METHODOLOGY

For this research multiple methods and models are been used. In this section several methods and models will be explained, and pointed out how they contribute and affect the research. The important part of this section is about the design choices that are being made. The overall goal of this research is to create a model in RIBASIM that would contribute to the allocation process for PJT II. In section 4, the results of the model will be explained. This section will only focus on the design part of the model.

## 3.1. WATER DEMAND METHOD

The water demand that is being used is determined by PJT II. Three water demands are defined, for each system/canal a unique water demand: West, North and East. These three demands are allocated at Curug (West and East) and Walahar (North) weir. Each of the three systems is subsequently built up out of several sub-systems. These sub-systems are built up out of water usages like: domestic water usage, industry and agricultural. A detailed explanation of the water demand structure can be found in appendix A.

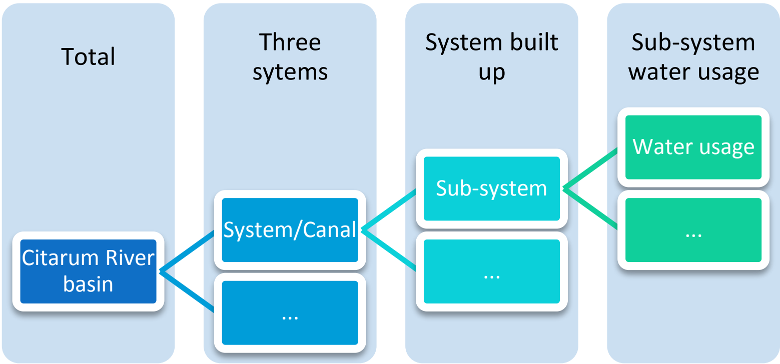


FIGURE 10: WATER DEMAND BUILT UP

In Figure 11, the water demand for each region is shown. The demand lines show similar trends, compared with the overall water demand. The big decrease in the north demand during the months august and September indicates that the influence of agricultural water use is big to the total water demand. The west system compared to the other two has a far more constant demand line. The influence of the dry and wet seasons does not look to affect the water demand too much. This is due to the relatively high domestic presence in the west demand.

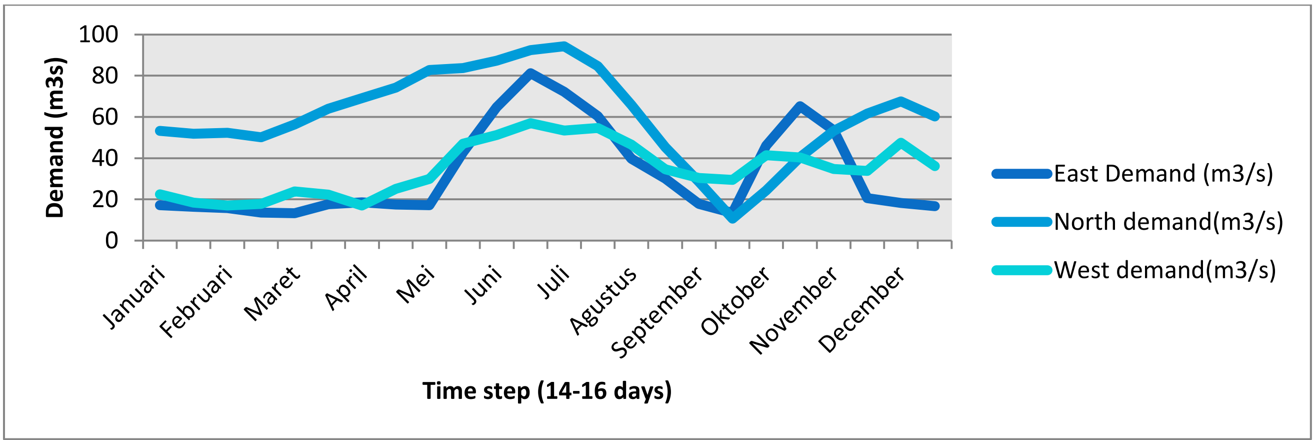


FIGURE 11: WATER DEMAND THREE SYSTEMS


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## 3.2. MODEL DESIGN

There is already a model existing that includes the river basin that is being focused in this case, this model is called the 6Cis model, the name is based on the fact that there are six big rivers in western java, Banten en Jakarta and the Indonesian word for river is Ci (Anon, 2012). In Figure 12, the work area of the 6Cis is shown. One disadvantage of using the 6Cis model is that the 6Cis is relatively slow because of its complexity. More nodes and links are included than are necessary for PJT II. Therefore, the model will be cropped into a new model that only includes the parts that are relevant. During the cropping of the model the effects of cutting away relations should noticed. Otherwise the model can lose much of its accuracy and level of detail. The creation of the new model does not only include cropping but also some modifications/adding new nodes and links.

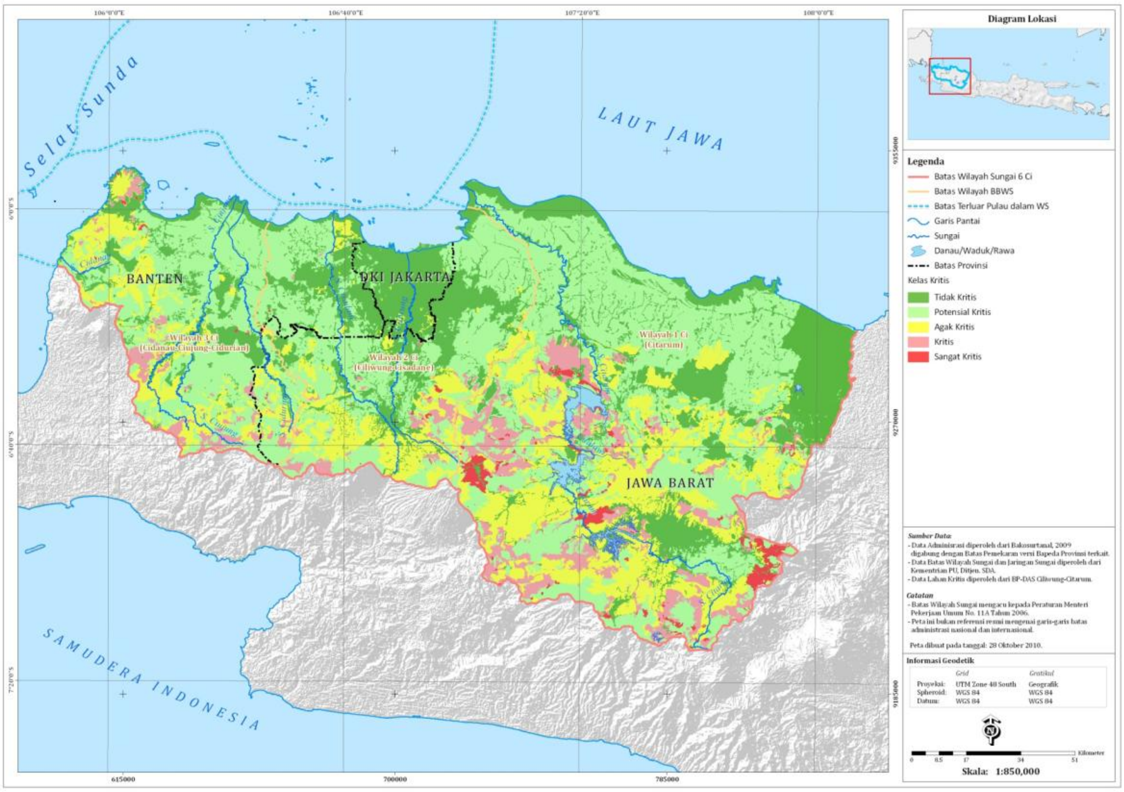


FIGURE 12: 6CIS WORK AREA

So basically a new model had to be designed, this is done using guidelines. In this study the design is based by answering the following questions, which are stated in (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008):

- What are the boundaries of the system?
- What degree of detail in the physical structure do we need?
- Which river stretches will be represented by individual links?
- Which river flows do we aggregate before feeding them into the network as a time series of inflow at a node?
- What water users do we take into account and with what degree of detail do we have to simulate them?
- What potential future measures do we intend to simulate, in terms of potential new reservoirs, canals, weirs, etc., and also in terms of operation?

### 3.2.1. WHAT ARE THE BOUNDARIES OF THE SYSTEM?

The boundaries of the system are limited to the boundaries of the jurisdiction that PJT II has, because PJT II cannot make policies about areas they do not control. The boundaries in the model start from the point the water flows into the system till the water leaves the system. The water can enter into the systems using two types of nodes:

i. *Fixed inflow,* a fixed discharge during the time series in the simulation. Each year the discharge will be the equal in the same time-step.
ii. *Variable inflow,* a time series of discharges for the whole simulation period. This is based on historical data with run-off models.

Water will eventually leave system by one type of node:

i. *Terminal node,* a node that represents the point where water leaves the system. A terminal node only records the water that leaves the system, it has no further preferences.

Between the inflow and the outflow nodes all the demand and control nodes are located. The boundaries of the system are normally set and fixed. The changes that occur between those boundaries are usually the different scenarios.

There are multiple ways to set the boundaries of the system, because of the fact that the current 6Cis model boundaries already have been set. Using the current boundaries will not hurt the model, given that it is already beyond the jurisdiction of PJT II. However, the question remains whether it makes sense to use to such broad boundaries.

There are two ways to design the upper stream part of the Citarum till Jatilhur Lake.

i. Keep the outlook of the upper stream part as designed in the 6Cis model. The benefit of this choice is that it can simulate the water supply for the Jatiluhur reservoir.
ii. Fixed inflow node directly to Jatiluhur Lake. PJT II has no control over the two upstream reservoirs; the only data PJTII receives is de outflow of those two reservoirs. The outflow of the Cirata reservoir can be transformed into a fixed inflow node which eventually will represent the whole upstream part of the Citarum. The advantage of this choice is that the conditions can easily be changed.

Water will leave the system after it has passed the demand nodes of the different areas in the system. Initially it is only important for PJT II to know if the water demand can be fully fulfilled and if not what measures could be used. So initially the focus is only the part that is interesting for PJT II. To determine where the terminal outflow nodes will be placed it is dependable on the required level of detail. The level of detail will be determined in section 3.2.2 and 3.2.4.

### 3.2.2. WHAT LEVEL OF DETAIL FOR THE PHYSICAL STRUCTURE?

During the process of applying the RIBASIM application to the current method, different levels of detail are being used. Each level of detail provides a specific amount of information regarding the consequences of the policy regarding water allocation. However, a high level of detail does not automatically mean that is better, because there is also a limit to the control level that PJT II has. The level of detail shall be chosen based on the fit for purpose. In Figure 13, the schematization that PJT II uses is shown. The schematization in RIBASIM is based on this layout; this guideline is used for determining the level of detail. The schematization in Figure 13 shows the relations that the canals have to the separate rivers. In the east system, there are some differences between the figure and the schematization built in RIBASIM. The amount of rivers in the east system and the amount of water demands are not equal: 7 rivers versus 5 water demands (PJTII, 2012).

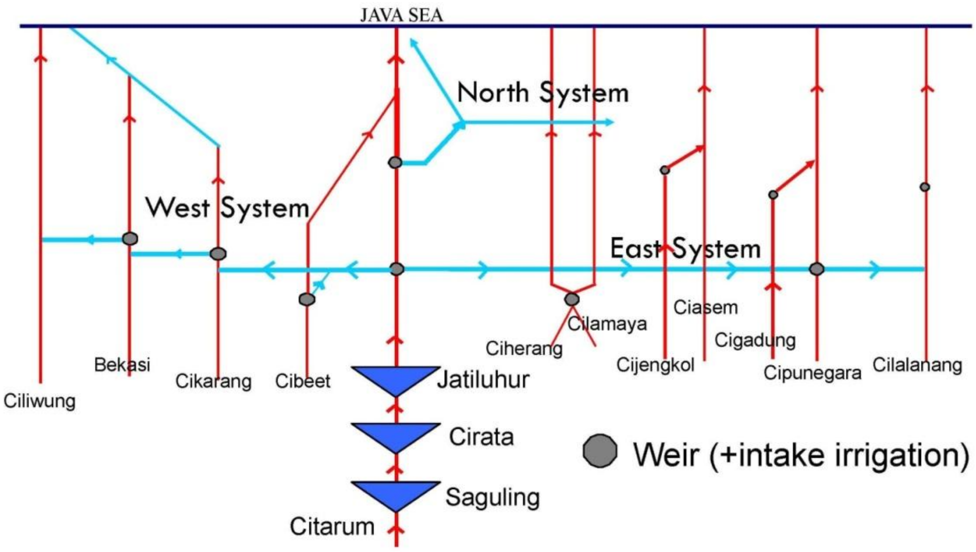


FIGURE 13: PJT II SCHEMATIZATION

### 3.2.3. WHICH RIVER STRETCHES?

The river stretches that will be represented by the links will be a part of the Citarum river basin infrastructure. This study only focuses on the part of the Citarum that is represented in the water demand schematization used by PJT II. In the previous section the level of detail is defined on sub-system level. This will mean that the water infrastructure needs to be designed on sub-system level; the water will leave the reservoir and flow till it arrives at the right sub-systems. Only the locations of the sub-systems are necessary, because the infrastructure of the sub-systems will not be represented. In the following part will be explained step by step what rivers will be represented, this will be done using the level of detail steps.

**System level:**

The main river stretch of the study area is the Citarum River; the rest of the basin consists out of tributaries of the Citarum. The Citarum floats from the Jatiluhur Lake via Curug- and Walahar-weir to the Java Sea.

**Region level:**

Connected to the Citarum are the three region systems: west, north and east. At the Curug weir both west and east canal are connected, and the north canal is connected to the Citarum via the Walahar weir. Parts of each of those three region systems are schematized in the model.

**Sub-region level:**

The sub-regions are limited to the weirs in the canals. As pointed out in Section X, the west an east canals have multiple weirs down stretch. Each of these weirs provides water for rivers delta's downstream. In Section 3.1 is the built up of the different river delta's explained. In the design of the model only the downstream part of each sub-river from the weir is taken into account.

In Figure 14 the three detail levels are shown in the network, each color represents a different category. This figure shows the clear distinguish between levels of detail on the network level. The system level is being represented by the red line, the line flows in the middle of the network. Attached to the system/red line are the three region/green lines. These lines are representing the three region systems as explained in section 3.1. The last type of lines and the ones attached to greens ones, are the sub-region levels. These lines represent the different sub-basins of each water demand.

TABLE 2: DESIGNED RIVER STRETCHES

| | | |
|---|---|---|
| Citarum | North | North System |
| | West | Cibeet |
| | | Cikarang |
| | | Bekasi |
| | | Jakarta |
| | East | Barugbug |
| | | Jengkol |
| | | Macan |
| | | Gadung |
| | | Salamdarma |

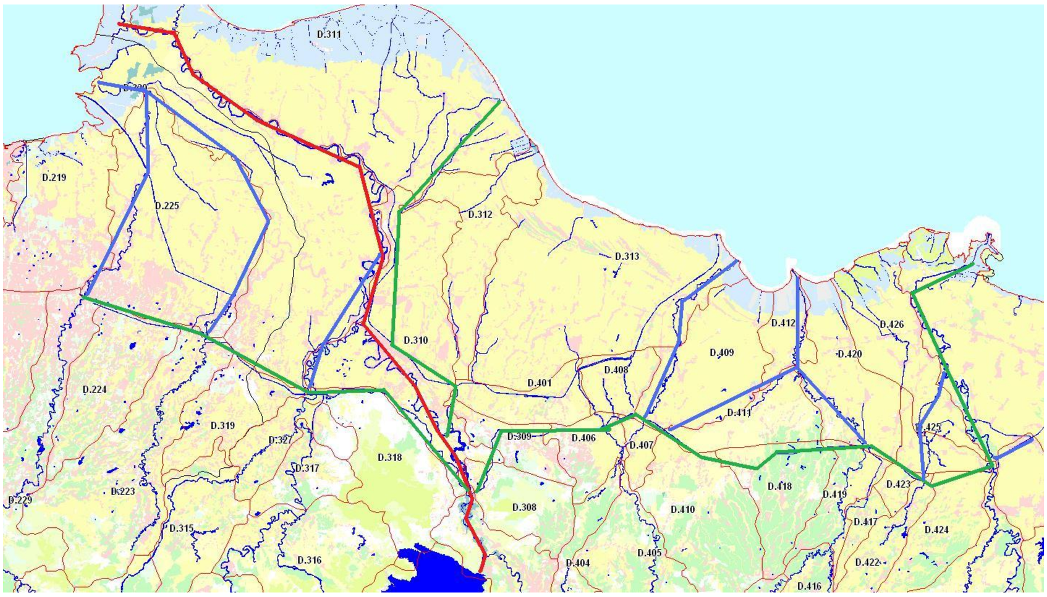


FIGURE 14: NETWORK LEVELS (RED=SYSTEM, GREEN=REGION AND BLUE = SUB-REGION)

### 3.2.4. WHICH AND WHAT LEVEL OF DETAIL WATER USERS?

The water users that will be taken into account are defined in the water demand model of PJT II. In the model that is used by PJT II, the water demand is built up step by step. The water demand that currently is used by PJT II can be seen in four layers. The lowest layer is the water demand on a specific location; an example is the domestic water usage in the Bekasi area, or the agricultural usage in the same area. When all these water usages are summed up in each unique area, the water demand of each sub-system is defined. All these sub-systems combined give the water demand for each separate system: West, North and East. The highest layer is the summation of these three water systems, and represents the water demand of the complete Citarum river basin. In Figure 15 an example of the schematization of these four layers is shown, not all the sub-systems and accompanying content is included, because that would have produced a too complex/unclear schematization.

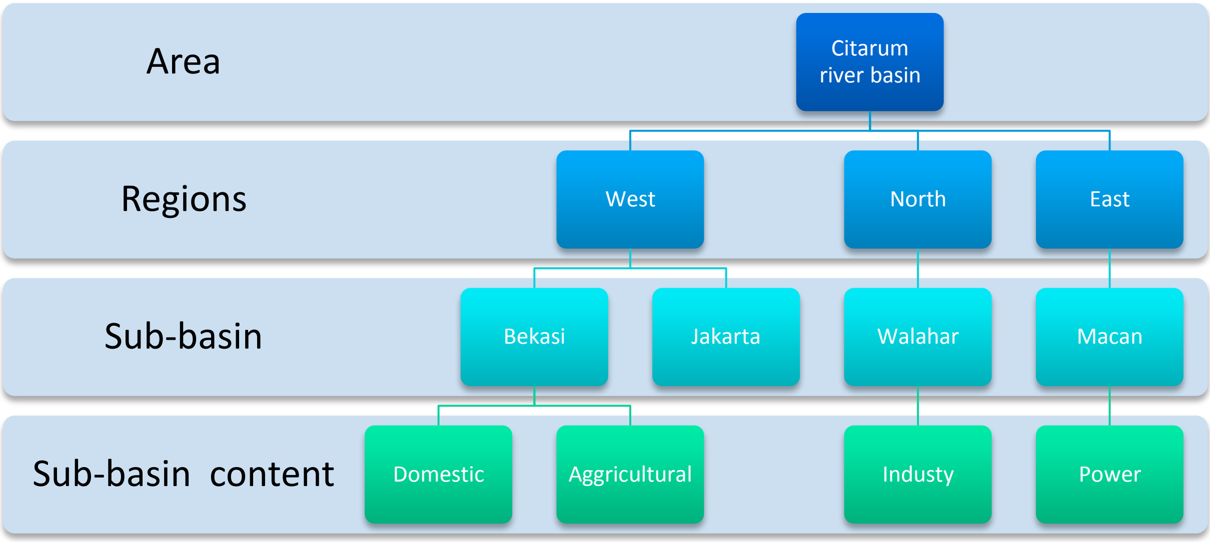


FIGURE 15: WATER DEMAND BUILT UP

As pointed out in section 3.2.2, the level of detail is restricted on the capabilities of PJT II. The physical capabilities of PJT II are restricted to the weirs on the sub-basin level (PJTII, 2012). Therefore, the water users on the sub-basin level will be used for this research. This means that the content of these sub-basins are not taken into account, but that these demands are added together and are considered as "one" water demand.

### 3.2.5. WHICH RIVER STRETCHES WILL BE AGGREGATED?

With aggregated river stretches, it is meant river stretches that are reduced to a couple of nodes instead of long scattered connections of links en nodes.

River stretches that will be aggregated are the upstream parts of the several sub-regions. As pointed out in appendix A, is the local water supply included in the water demand of each sub-region. The local water supply is provided as a one year time series. It is unnecessary to keep the current upstream part till the weir, because: 1 there is no control over this area 2 it will not have influence on the actual supply flow. The river stretches will be aggregated to fixed inflow nodes that contain the local supply time series from the demand method. In section 3.3.1.1, more details will be revealed about the fixed inflow nodes.

### 3.2.6. POTENTIAL MEASURES

In this section will the different scenarios that are used are pointed out. A distinguish between the changes to infrastructure/policies/scenario's is made. The "default" scenario is the scenario corresponding with the preferences in the "BC-10" case of the 6Cis model.

**Infrastructure:**

At this moment a project is going on to construct above-ground pipelines from the Jatiluhur reservoir to the public water supply in Jakarta (AID, 2012). Surface water around Jakarta is internationally known as one of the most polluted ones. The contaminated water is a result of the several domestic and industrial users of water of the west system canal. Preventing clear drink water to get contaminated, plus to be ensured that enough water is supplied to Jakarta, has the administration of Jakarta do deciding that a pipeline will be build (Setiawati, 2009). The pipelines will be built up in three stages, in the first stage an additional 5 m3/s will be flowing to Jakarta by one pipe, in the 2nd another 5 m/3s in a second pipeline, and after the third pipe is realized with 5 m3/s the total will be 15 m3/s (AID, 2012). The original water supply for Jakarta remains the same, the pipeline is just extra, and in 2030 the goal is to have a water supply of 30 m3/s.

The pipeline will be represented in RIBASIM as a new water demand site, which is connected at the beginning of the west canal. Figure 16 shows how the canal is designed in RIBASIM.

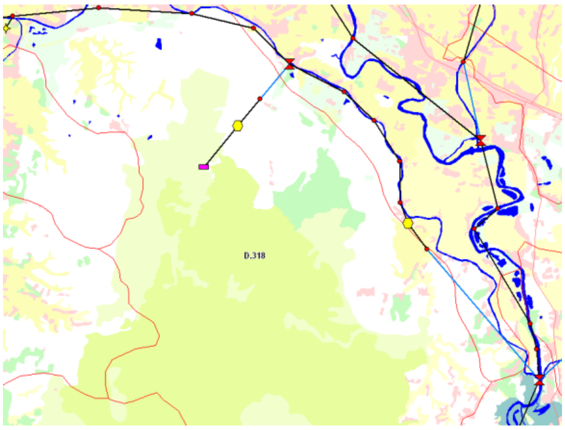

FIGURE 16: CANAL DESIGN RIBASIM

**Hydrologic Scenarios**

Three different hydrological scenarios are set up; these scenarios differ in the water supply part. The water demand in each scenario will be kept the same, to make sure that the results of the different scenarios can be compared. In appendix D, the supply per node is shown.

- 1. Dry year (10% less water supply)
- 2. Normal year ( 0% change to the water supply)
- 3. Wet year (10% more water supply)



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## 3.3. NODE INPUT DATA

In section 3.2 the network of the model is determined and designed; in this section the properties of the nodes will be defined. There are three main node types: layout (Lay-Out Nodes), -demand (3.3.2) and –control nodes (3.3.3). In each subsection of this section the properties of these nodes will be explained, and how the nodes operate with their properties.

### 3.3.1. LAY-OUT NODES

In RIBASIM there are two different inflow nodes: variable- and fixed inflow nodes. The variable inflow nodes are used for simulation of the "expected" inflow over a large window of time, and fixed inflows are used for a one year time series.

#### 3.3.1.1. FIXED INFLOW NODES:

As explained in appendix A, the water demand that PJT II determines includes a local water supply for each sub-system. By taking the local water supply out of the water demand and place it in a separate inflow node, scenario's that include a change in the water supply can be carried out quickly. Another reason to separate the supply from the demand is that in the current method the demand is set to zero if the supply outreaches the demand. But as a result the supplied water cannot be used in other downstream areas where there maybe is still need. The choice of separating these two, will give PJT II more options on the possible allocation of water.

The local water supply is determined for each sub-system excluding the north system. The only water supplier for the north system is the Citarum, and therefore no local water supply is defined. The west and east system however do include local water supply for each of their sub-systems. In appendix D, all the water supplies for each sub-system are shown. These water supplies are directly taken out of the water demand documents, no further adjustments are being made to the water supply. The reason that no extra adjustments are being made, is because the values have to be the same as used in the current method. The water supply is subtracted of the gross water demand after all the margin adjustments are been made. Figure 17 shows the total local water supply for both the east and west system.

The fixed inflow nodes are not connected or related to upstream terminal nodes. Therefore only one equation is applicable to the node (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008):

$$Q_{down}[t] = Q_{infix}[t] - Q_{misc,act}[t]$$

TABLE 3: FIXED INFLOW NODE PROPERTIES

| | Explenation | Value in model |
|---|---|---|
| $Q_{down}[t]$ (m3/s) | Downstream flow | - |
| $Q_{infix}[t]$ (m3/s) | Fixed inflow | Spec. model data |
| $Q_{misc,act}[t]$ (m3/s) | Upst. Water consumption | 0 |

The inflow flows that are specified in the model data will be equal to the actual flows that RIBASIM simulates out of the fixed inflow nodes.

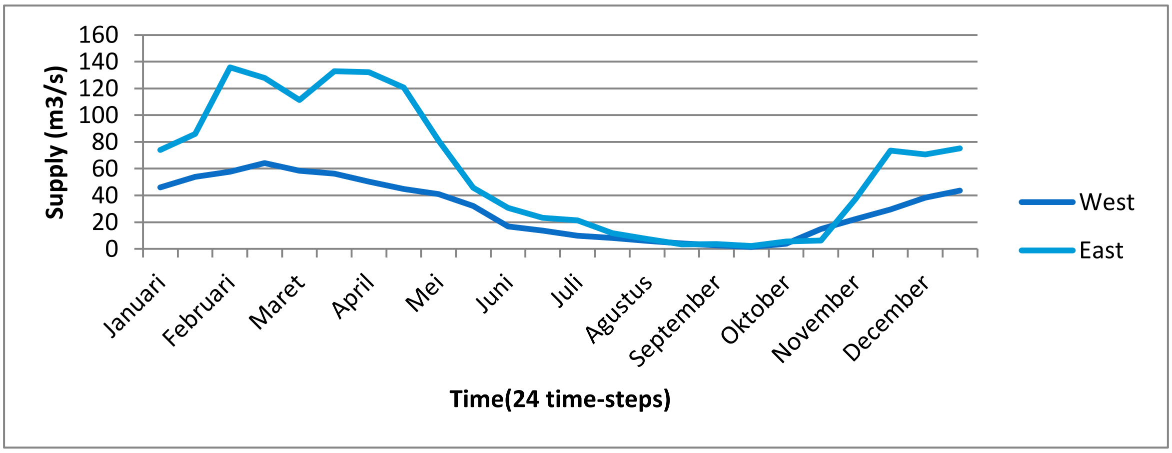



FIGURE 17: LOCAL WATER SUPPLY EAST VS. WEST

#### 3.3.1.2. TERMINAL NODES

According to (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008), terminal nodes are categorized as lay-out nodes. The only function of a terminal node is to record the water that leaves the system, and because the terminal nodes in this model are not connected to variable inflow nodes the only equation applicable is:

$$Q_{out}[t] = Q_{up}[t]$$

| | Explanation: |
|---|---|
| $Q_{out}[t]$ (m3/s) | Flow leaving the system |
| $Q_{up}[t]$ (m3/s) | Flow in upstream link |

One new terminal node is added to the network, to cover the drink water supply for Jakarta. The rest of the terminal nodes that were initially placed in the 6Cis model keep their location.

### 3.3.2. WATER DEMAND NODES

Section 3.1 describes how the water demand is built up. The water demand can be seen on three levels: area, region and sub-region. As section 3.2.4 points out, the water demand for this design will be on the sub-region level of detail. The result will be that the demand for each region will be appointed to the different sub-regions. So instead only having a water demand for the west system, there will be now a water demand for Jakart, Bekasi, Cikarang en Cibeet. The water demand of each region will be explained in a subsection.

The node type that is been used to visualize water demand, is the public water demand node. The public water supply is built for simulating the water demand of industries and domestic use. It provides the possibility to specify a water demand time series that is the same for every year. This study is only focused on surface water, so ground water flows are default or zero. The equations that are being used by RIBASIM to determine the flows that are applicable for the public water demand node.

An overview of the explicit demand that each demand node has is shown in appendix D.

#### 3.3.2.1. WEST SYSTEM

The water demand of the west system is built up of four different water demands: DKI Jakarta, Bekasi, Cikarang and Cibeet. These four water demands including the extra margin for physical losses present the water demand for the west system that will be supplied from the Curug weir. In the model five demand nodes are defined: Jakarta, Bekasi, Cikarang Cibeet and the error margin one. In Figure 18 a schematization of the west system is shown. The single circles represent the demand nodes; the double circles represent the local supply of each sub-region. The squares represent the weirs in the canal.

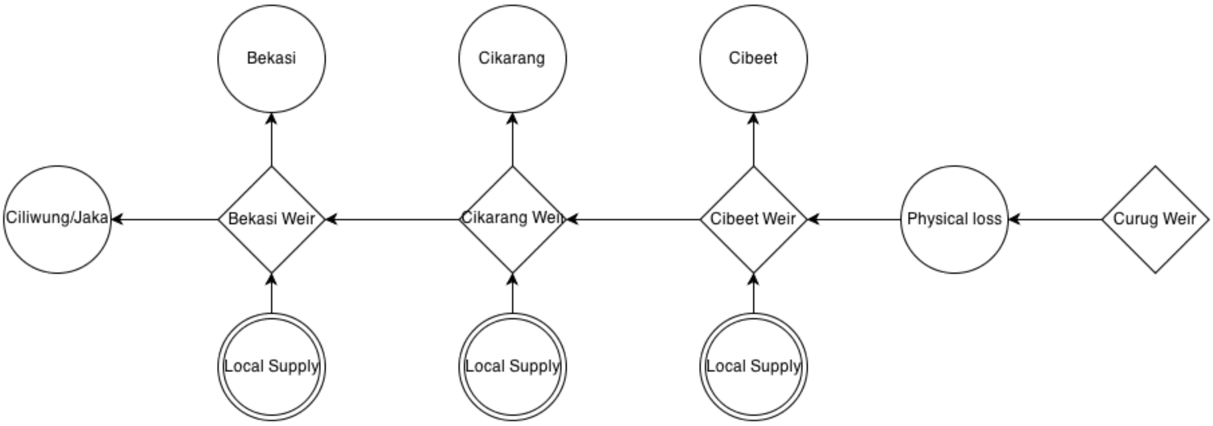



FIGURE 18: SCHEMATIZATION WEST SYSTEM

#### 3.3.2.2. NORTH SYSTEM

The north system does not contain several sub-regions but is built up as one big demand node. Therefore the total water demand of the north system is used that is stated in Section X. The water demand node of the north system is via a couple of confluence nodes connected to Walahar weir. In contrast to the east and west system, the north system does not have a separate demand node to represent the physical loss.

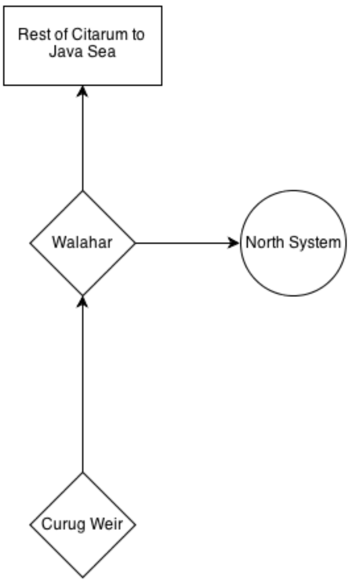



FIGURE 19: SCHEMATIZATION NORTH SYSTEM

### 3.3.2.3. EAST SYSTEM

The east system is built like the west system out of several different water demands: Salamdarma, Gadung, Macan, Jengkol and Barubug. Each of these five sub-rivers is represented in the model as an individual water demand node. Like the west system, the east system also includes an error margin for physical losses; this separate demand node is connected directly at the beginning of the canal.

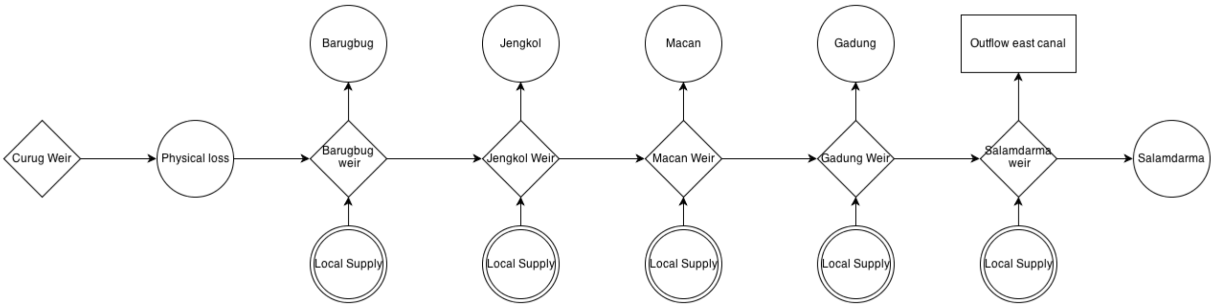



FIGURE 20: SCHEMATIZATION EAST SYSTEM

**Public water demand nodes**

$$Dnet[t] = Dex[t]$$

$$D[t] = Dnet[t] * \frac{100}{100 - L}$$

$$D[t] = Dsw[t] + Dgw[t]$$

$$Qpws[t] = MINIMUM(D[t], Qupsw[t] + Qupgw[t]$$

$$Qreturnsw[t] = Psw[t] * \frac{Qpws[t]}{100}$$

$$Qdown[t] = Qupsw[t] + Qupgw[t] - Qpws[t] + Qreturnsw[t]$$

| | Explanation | Value in model |
|---|---|---|
| $Dnet[t]$ (m3/s) | Net pub. Wat. Dem. | - |
| $Dex[t]$ (m3/s) | Explicit wat. Dem. | Given in appendix D |
| $D[t]$ (m3/s) | Gr. Pub. Wat. Dem. | - |
| L (%) | Distribution loss | 0 |
| $Dsw[t]$ (m3/s) | Dem. Surface water. | The only one applicable. |
| $Dgw[t]$ (m3/s) | Dem. Gr. Water | - |
| $Qpws[t]$ (m3/s) | Allocated water | - |
| $Qreturnsw[t]$ (m3/s) | Return flow surf. Water. | - |
| $Psw[t]$ (%) | Return flow surf. Percentage | 0 |
| $Qupsw[t]$ (m3/s) | Upstream surf. Water | - |
| $Qupgw[t]$ (m3/s) | Upstream ground water. | 0 |
| $Qdown[t]$ (m3/s) | Downstream flow | - |

### 3.3.3. CONTROL AND INFRASTRUCTURE NODES

**Confluence nodes**

Confluence nodes are used to connect links, without having an influence on the water balance. A confluence node can be connected to multiple upstream links, but only to one downstream link (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008). No extra data is required when adding or changing a confluence node. The downstream flow is equal to the sum of the upstream flows. The only equation that is applicable to the confluence node:

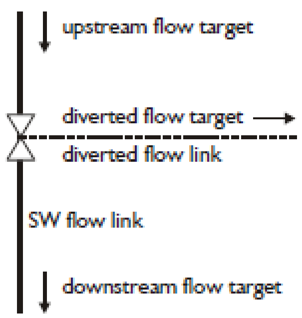
$$Q_{down}[t] = \sum Q_{upi}[t] \qquad for\ i = 1 \ldots n$$

| | Explanation |
|---|---|
| I | Upstream flow link index |
| N | Number of upstream flows |
| $Q_{down}[t]$ (m3/s) | Downstream flow |
| $Q_{upi}[t]$ (m3/s) | Upstream flow |

**Diversion nodes**

A diversion node represents a site where water is diverted from the main link (in this case the Citarum or one of the three canals) to satisfy downstream water demands. Diversion nodes are used to represent weirs; in this case there are several weirs, which will be represented by a diversion node. The flow that is diverted from the main link depends on a number of factors (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008):

- Available water in upstream link
- Operation policy
- Physical and operational characteristics of the diverted link




As pointed out in section 2.1.3, the water allocation process is carried out in two phases: target setting- and allocation phase. Diversion nodes are used for allocating water, and therefore the equations applicable are also separated for both phases.

*Target setting phase:*

A diversion node is always connected to three links: 1 upstream flow, 2 diverted flow and 3 the downstream flow. For each of those three flows a target has to be set. In the target phase the diverted and downstream flow demand are combined, so one upstream water demand is defined at the diversion node (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008):

$$Qtarg_{sw}[t] = Qtarg_{sw}{}'[t] + D[t]$$

$$Qtarg_i[t] = MINIMUM(Cap_i[t], Qtarg_i'[t] + D[t]$$

$$Qtarg_{up}[t] = MAXIMUM(f_i^{-1}(Qtarg_i[t]), \sum Qtarg_i[t] + Qtarg_{sw})$$

*Allocation phase*

After the target setting phase the allocation phase is carried out. During this phase water is simulated trough the network of nodes. In this phase becomes clear whether the supply covers the demand or not.

$$Q_i[t] = Minimum(Cap_i[t], Qtarg_i[t], f_i(Qup[t]))$$

$$Q_{sw}[t] = Qup[t] - \sum Q_i[t]$$

| | Explanation |
|---|---|
| I | Diverted flow index |
| $Qtarg_{sw}[t]$ (m3/s) | Updated target flow downstream |
| $Qtarg_{sw}{}'[t]$ (m3/s) | Target flow downstream |
| $D[t]$ (m3/s) | Demand of downstream demand node |
| $Qtarg_i[t]$ (m3/s) | Updated target flow at diverted flow link |
| $Cap_i[t]$ (m3/s) | Maximum diverted flow |
| $Qtarg_i'[t]$ (m3/s) | Target flow at diverted link i |
| $Qtarg_{up}[t]$ (m3/s) | Upstream target flow |
| $f_i^{-1}$ (l) | Diverted flow relation |
| $Q_i[t]$ (m3/s) | Flow in diverted link |
| $Qup[t]$ (m3/s) | Upstream flow |
| $Q_{sw}[t]$ (m3/s) | Flow in downstream link |

Basically a diversion node is placed on every location water has to be allocated, except for the Jatiluhur reservoir. An overview of all the diversion nodes and the direct demand it supplies can be seen in Table 4. The only diversion node that supplies two demands is the Bekasi node. Originally the canal flows till Jakarta, so the Bekasi node is the last one of the west canal which does have an influence on the allocation.

TABLE 4: DIVERSION NODE PROPERTIES

| Number | System: | Name: | Supplies | RIBASIM Name: |
|---|---|---|---|---|
| 1 | | Curug | West- & East Canal | CIT _Curug_Weir |
| 2 | | Walahar | North Canal | CIT _Walahar_Weir |
| 3 | West | Cibeet | Cibeet | CIT _WTC_Cibeet_Weir |
| 4 | West | Cikarang | Cikarang | CIT _WTC_Cikarang_Weir |
| 5 | West | Bekasi | Bekasi and Jakarta | CIT _WTC_Bekasi_Weir |
| 6 | East | Barugbug | Barugbug | CIT _ETC_Barugbug_Weir |
| 7 | East | Jengkol | Jengkol | CIT _ETC_Jengkol_Weir |
| 8 | East | Macan | Macan | CIT _ETC_Macan_Weir |
| 9 | East | Gadung | Gadung | CIT_ETC_Gadung_Weir |
| 10 | East | Salamdarma | Salamdarma | CIT_ETC_Salamdarma_Weir |

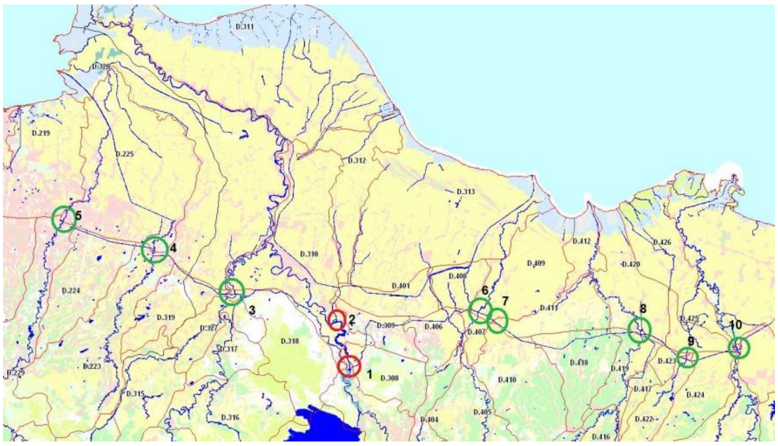


FIGURE 21: DIVERSION NODES LOCATIONS

**Surface water reservoir node**

The surface water reservoir node represents river basin reservoirs, places were (high) volumes of water are stored and the water outflow is controlled in such a way that the available water is used in the most efficient way for the purposes (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008).

- Supply water for downstream demand nodes
- Electricity generation
- Flood control

Each reservoir has its own characteristics that influence the operation and behavior of the reservoir. Hydrological (full reservoir level, main gate level, maximum capacity, etc...), Hydropower (Turbine intake level, turbine capacity etc...) operation rule curves, hydrological data and miscellaneous data; the first two characteristics influence the operation of the reservoir but are not likely to be changed often. The operation rules curves are set up as part of the reservoir operation, these curves include minimum and maximum storage at any given time. The hydrological and miscellaneous datasets contains information like: time series for rainfall and evaporation and the initial reservoir level at the beginning of the simulation.

Reservoirs play an important role in the water resources management, but in this study there will not be further discussed. There are currently already studies underway on the reservoir operation of the three reservoirs (Jatiluhur, Cirata & Saguling). In this model, nothing has changed has been changed to the reservoirs, they are equal to the reservoirs from the 6cis. Therefore this node is not discussed on its equations, because that is not relevant for this study.

### 3.3.4. LINKS

In this section the different links that are used will be explained. In appendix E, there is an overview of the total numbers of links in each category shown.

**Surface water flow**

The most standard used link is the surface water flow. These are the links, which cannot be categorized in any of the other link types. The surface water flow link has to types:

- Canal or Pipeline, this link has a yearly time series with a limited capacity
- River: no capacity limits

The capacity is taken into account, during the second phase (target setting). The following equation is only applicable when the surface water link represents a canal or pipeline with a flow capacity.

$$Qdown[t] \leq Qcap[t]$$

| | Explanation |
|---|---|
| T | Time step index |
| $Qdown[t]\ \left(\frac{m3}{s}\right)$ | Flow in the downstream link |
| $Qcap[t]\ \left(\frac{m3}{s}\right)$ | The limited flow capacity |

The west and east canal have both a changing discharge capacity, the capacity changes further downstream. Figure 22, shows both decreasing discharge capacities. The horizontal axes represent the “relative” distance from Curug weir downstream. The west canal line in

Figure 22 is longer because the west canal is built up from more different channel capacities, this figure does not tell anything about the length of both canals. The horizontal lines show the limited constrain in Curug weir for both canals, this shows that the capacity of the canal is in the beginning larger than the maximum diverted flow from Curug, but further downstream becomes lower than the maximum water flow. One exception for the canal capacity is the link between the fixed inflow and diversion node. As pointed out in section 3.3.3, a diversion node can only have one upstream flow; therefore the inflow node is connected one node before the diversion node. A schematization of the new situation is show in Figure 23.

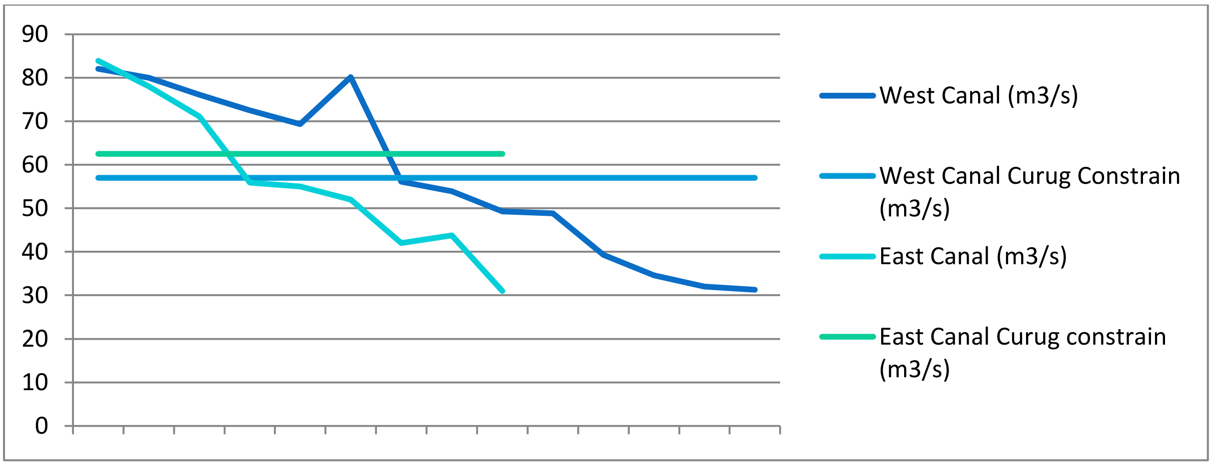



FIGURE 22: RELATION CANAL CAPACITY

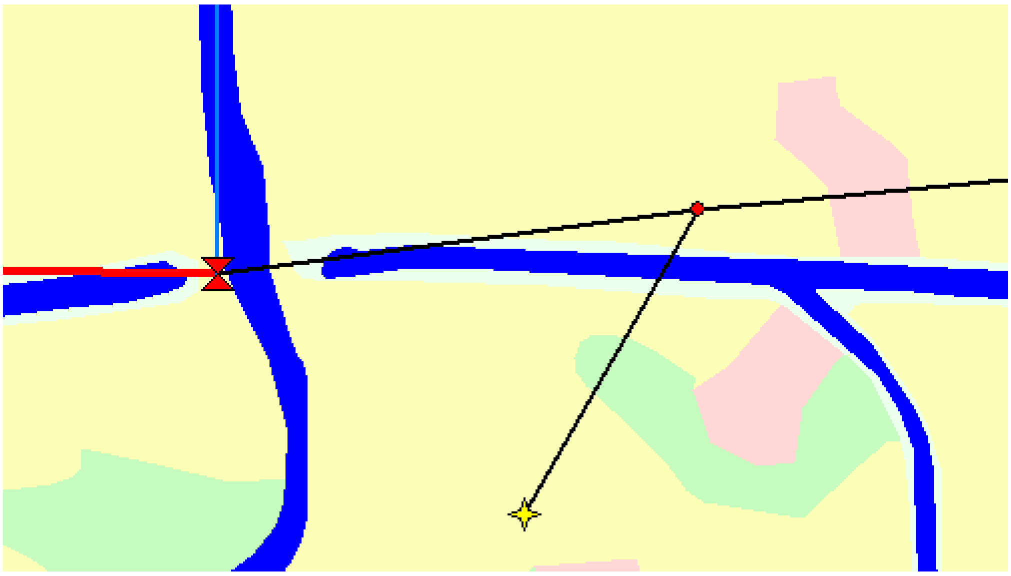


FIGURE 23: NO LINK CAPACITY

**Diverted water flow**

The diverted water flow is the link that is diverted from the diversion link stated in section 3.3.3. This type of link is being used to represent the water flows that are diverted from a main stream canal or pipeline.

The maximum discharge the diverted water flow can be specified in two ways; both settings have to be set. The lowest of both flows is the maximum constrain (Krogt, RIBASIM Version 7.00, Technical Reference Manual, 2008).

- Annual time series (m3/s).
- The relation between the upstream- and diverted flow in m3/s.

The relation between the maximum diverted flow and upstream flow of the diversion node has to be specified. In the default settings, the diverted flow will be zero, independent of the upstream flow. Underneath Table 5 the settings of the upstream and maximum diverted flow are shown, the settings are set that this relationship has no constrain on the maximum diverted flow. With settings from Table 5, the diverted flow can minimum and maximum be equal to the upstream flow.

TABLE 5: DIVERTED FLOW RELATION

| Upstream flow [m3/s] | Diverted flow [m3/s] |
|---|---|
| 0 | 0 |
| 1000 | 1000 |
| -1 | -1 |

The operation of the diverted flow has two switches.

- *Online adjustable gate setting:*
    - ON: Diversion target equals target flow set in target setting phase
    - OFF: Target flow is equal to the maximum diverted flow
- *Operate on downstream demand:*
    - ON: The diversion target flow can be updated in allocation phase.
    - OFF: The diversion target flow is set during the target setting phase only, and is not updated during the allocation phase.

Both switches are turned on in the model.

## 3.4. REST OF INPUT DATA

The simulation case that was being used is “BC-10” out of the 6Cis model. The most important data of this case is hydrologic scenario 015 that is being used is the rainfall-runoff flows in the upstream part of the Citarum. In the BC-10 file a hydrologic series is included that is been used on the inflow side of Jatiluhur reservoir. The nodes and links that were upstream in the beginning of the BC-10 scenario remained unaffected of the modifications/building that kept place. The time series of the hydrological data ranges from 1951 till 1979. This period is also used in the simulations for testing the model.

# 4. RESULTS RIBASIM CALCULATIONS

In this section the results of the RIBASIM model are published. First of all in 4.1 the outlook of the model is shown, section 4.2 provides the results of the outcomes of the simulations. There are multiple ways to analyze the water balance in the area, but for this research the most interesting one is the possible water shortages in the demand nodes. Supplying sufficient water for the demands is what PJT II is most interested about. When running the simulation, RIBASIM supplies water to nodes that are demanding water.  Due to different circumstances or situations it may happen that the total demand outreaches the total supply. The difference between the demand and the actual supply is the water shortage.

The water shortage can be expressed in two ways:

- Shortage in $\frac{m^3}{s}$
- Percentage of demand supply ratio

$$Water\ shortage(\frac{m^3}{s}) = Water\ demand(\frac{m^3}{s}) - Water\ supplied(\frac{m^3}{s})$$

$$Ratio(\%) = \frac{Supply(\frac{m^3}{s})}{Demand(\frac{m^3}{s})} * 100\%$$

Both numbers provide different information about the water shortage. The shortage expressed in cubic meters per second (m3/s) gives insight in the actual shortage, while the shortage ratio shows how much of the demand is not fulfilled. As an illustration to show the different insight both numbers provide, an example: suggest that the water shortage in m3 / s is low, this could mean that there is a low deficit. But if the total demand being low as well, then the deficit very high in percentage terms. And the opposite could also be possible that there is a high shortage in terms of m3/s, but that the shortage for the particular demand node relatively low is.

The goal for PJT II is to have none or at least try to minimize water shortage. Water shortages can lead for example to monetary damages due to insufficient water cover in the (agricultural) industry. And even more dangerous consequences if there is insufficient water available for domestic usage.

Multiple simulations are carried out that have an effect on the outcome. In Table 6, the different simulations are shown plus their respective “change” towards the initial base case. In this section only results of the “base case” are shown, the results of the other three cases can be found in appendix G.

Table 6: Simulation Cases

| Name simulation | Difference |
|---|---|
| “Basecase-10” | -10% fixed inflow |
| “Basecase” | Standard case |
| “Basecase+10” | +10% fixed inflow |
| “Basecase+pipeline(s)” | Pipeline Jakarta |

For this study, the actual results are not that important, but this is only to show what kind of information the model can give to policymakers.

## 4.1. MODEL OUTLOOK

The schematization that is set up in section 3.2 is translated into a RIBASIM model. This is done by using the different nodes and links that are explained in section 3.3. In Figure 24, a part of the model is shown. This part comes directly after Jatiluhur reservoir; all the demand and supply nodes that are defined are shown in the figure. An overview of the full network is shown in Figure 24 and overviews of each separate system are shown in appendix C.

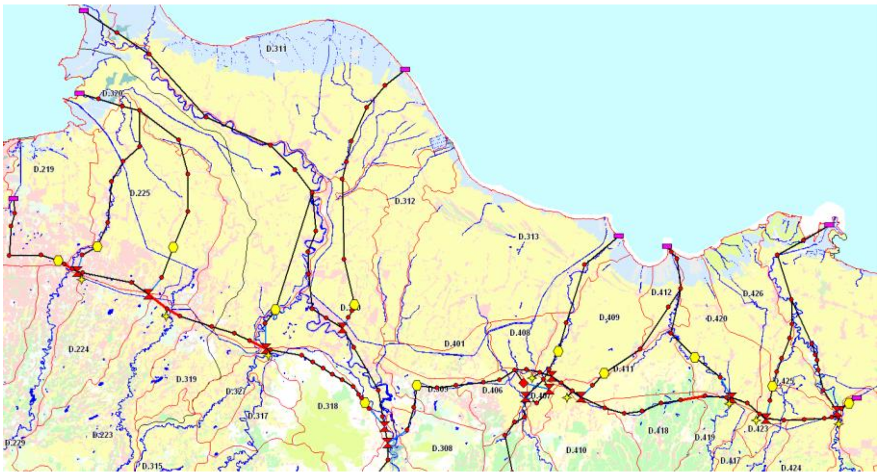


FIGURE 24: NETWORK DESIGN

## 4.2. RESULTS

### 4.2.1. WATER SHORTAGES

**West System**

In Figure 25 is the water shortage shown for all the western canal demand nodes in m3/s. What stands out is that in the whole simulation periods [1951-1978], only one time shortage occurs during that specific period. The drink water demand for Jakarta has insufficient water supply during that period. In appendix G, the water shortages for the west system are shown with different local inflows, the results are as expected more shortages when the inflow is lower and less shortage with a higher inflow.

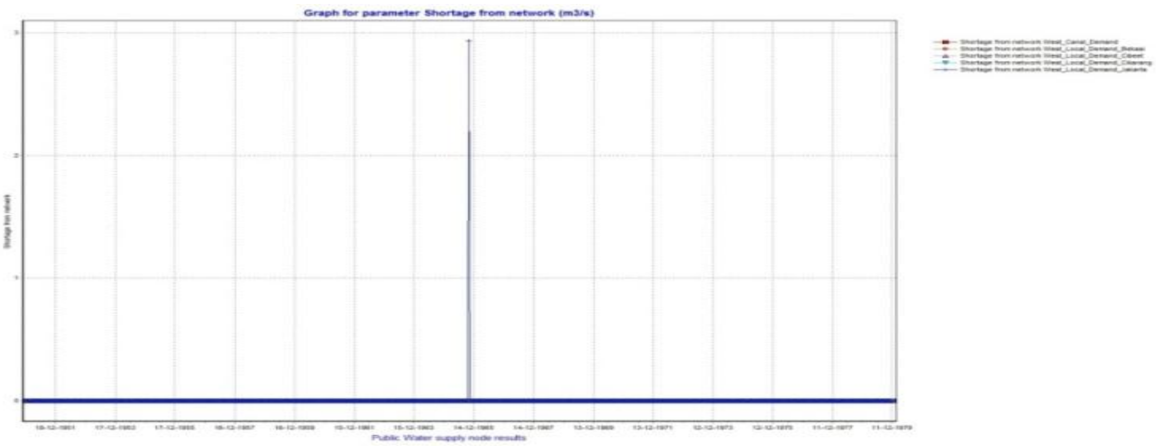



FIGURE 25: WEST SYSTEM WATER SHORTAGE [1951-1978]



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**East System**

Like the west canal, the different demand nodes show similar shortage patterns. In appendix G the water shortages are shown when different scenarios are being applied. The east system is the only system of the three, which has an annual returning water shortage in their system. Figure 26 meanwhile shows the water shortage for one year [1951]. The three demand nodes which encounter shortage are located at the eastern end of the channel; this corresponds to the theory that the most downstream demand nodes are likely the first ones to encounter first shortage at equal priorities. Another possible cause for the water shortage in the east system is that the total demand of the east system outreaches the capabilities at Curug weir, as shown in appendix G, the demand is higher than the maximum diverted flow; these months corresponded with the month's shortage in the east system.

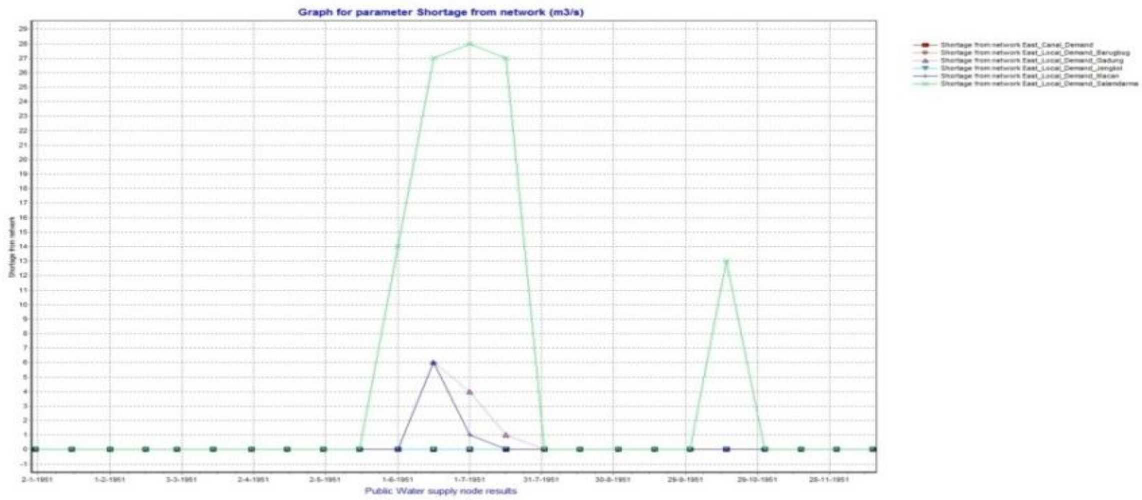
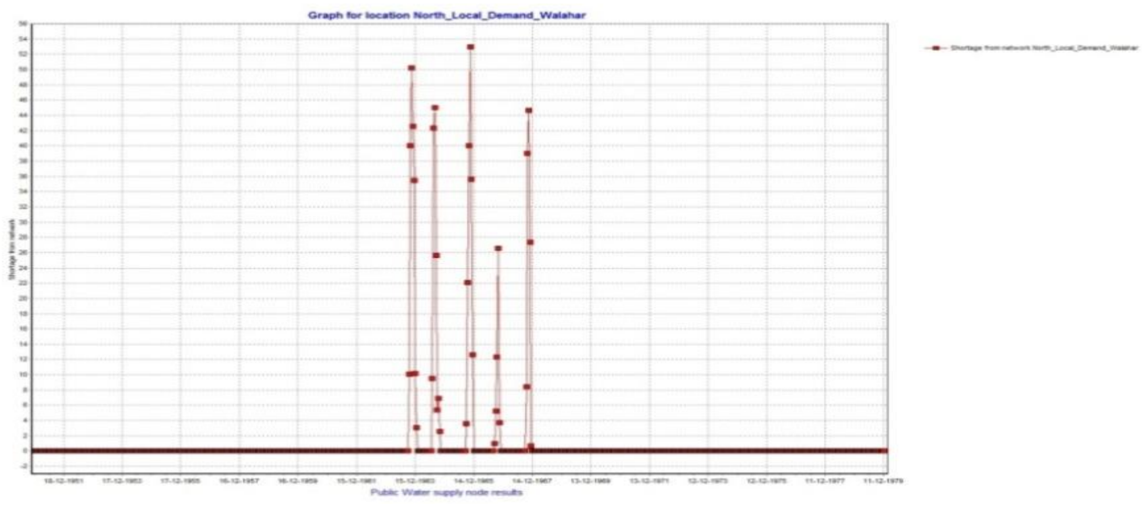



FIGURE 26: EAST SYSTEM WATER SHORTAGE [1951]

**North System**

The north system's water shortage is shown in Figure 27. Five times does the demand outreach the supply, the water shortage occurs in five straight years [1963-1967]. The north system does not have a fixed inflow that can be changed in different scenarios, but the effects of the scenarios are also visible. When the local inflow decreases, the demand of the west and east canal to Jatiluhur increases, this has an effect on the available water for the North system. In the -10% scenario the shortage increases with approximately 3 m3/s for the same period, in the wet scenario (+10%) it decreases compared to the base case with 3 to 4 m3/s. With the realization of the pipeline(s) the water shortage also increases, in the maximum situation five times the demand/supply ratio is zero.

FIGURE 27: NORTH SYSTEM SHORTAGE [1951-1978]



## 4.2.2. RESERVOIR BEHAVIOUR

**Jatiluhur reservoir**

Figure 28 shows the behavior of the Jatiluhur reservoir for the first two years of the simulation [1951-1952] in the base case. The pink line represents the target level that is defined in the SOP. The red line represents the actual water level at the end of each time step, and at last the orange line shows the level when reservoir is full and will spoil over. The “actual level at the end of the time step” is the only line that can be different each year; the full reservoir and target level are defined on a one year time period as pointed out in section 3.3.3. The water level of Jatiluhur reservoir is not the same in both years, the first year is probably a more dryer year than the second because of the low water level at the end of year one.

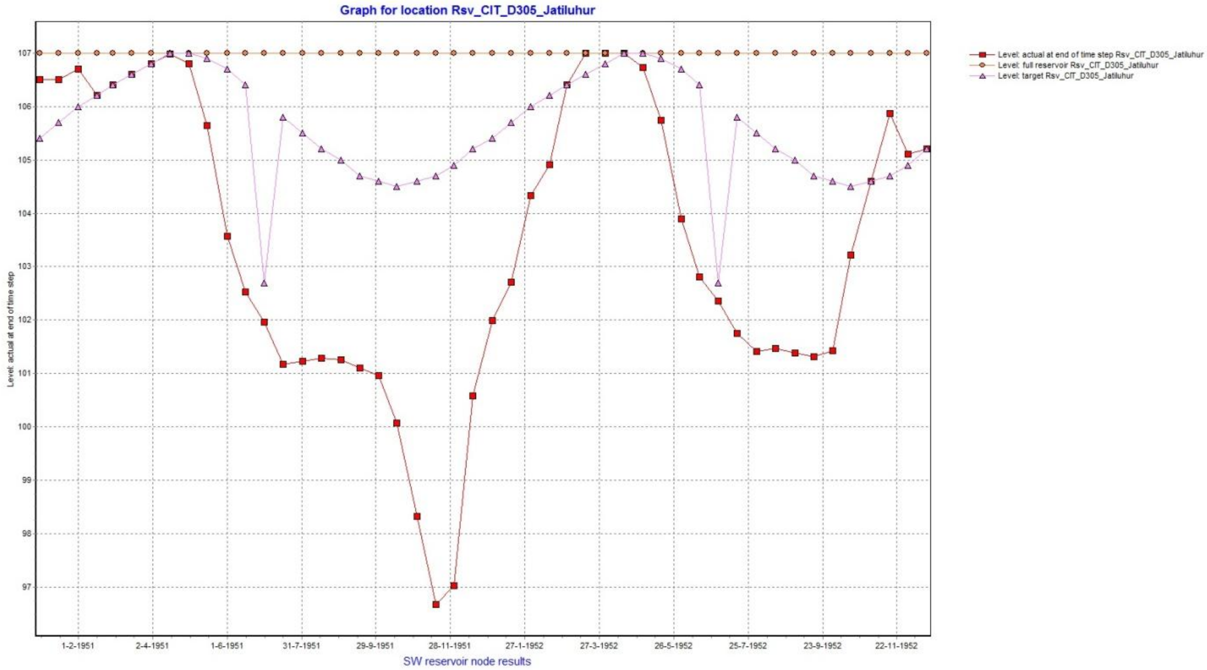



FIGURE 28: RESULT JATILUHUR RESERVOIR

In appendix G, the water levels of Jatiluhur reservoir are shown for the other scenarios. What stands out is that the minimum of the actual water level differs in each scenario; this illustrates the fact that the actual outflow of the reservoir is based on the water demand downstream. In the “normal” scenario the minimum in 1951 is just beneath 97 meters, in the dry scenario it reaches 96 meters and in the wet period its minimum is around 97,5 meters. The water level of the reservoir changes when the demand or supply also downstream changes. The same results happen when the scenarios with the pipeline(s) are executed, in the final stage (+15m3/s) the minimum for the reservoir in the first two ears reaches almost 95 meters.

## 4.2.3. WEIR FLOWS

RIBASIM records all water flows in each link or node. Therefore it also gives the possibility to gather information about the diversion nodes. In Figure 29 and Figure 30 are the flows in Walahar- and Curug-weir shown for the first two years of the simulation. The top line (pink) shows the inflow of the upstream link, the red line represents the diverted flow and the orange line shows the outflow to the downstream link. The diverted and downstream flows summed are equal to the inflow flow.

$$Inflow\ flow[\frac{m3}{s}] = Diverted\ flow[\frac{m3}{s}] + Downstream\ flow[\frac{m3}{s}]$$

Between both weirs there are no links or nodes located that could cause new inflow or outflow. Therefore, the inflow of Walahar weir should be equal to the downstream flow of Curug weir, comparing both figures shows that indeed the outflow of Curug is equal to the inflow Walahar. It also shows that the downstream flow of Walahar weir (rest of Citarum) is sometimes equal to zero, what shows that the reservoir is not at the target level, otherwise it would be spilling.

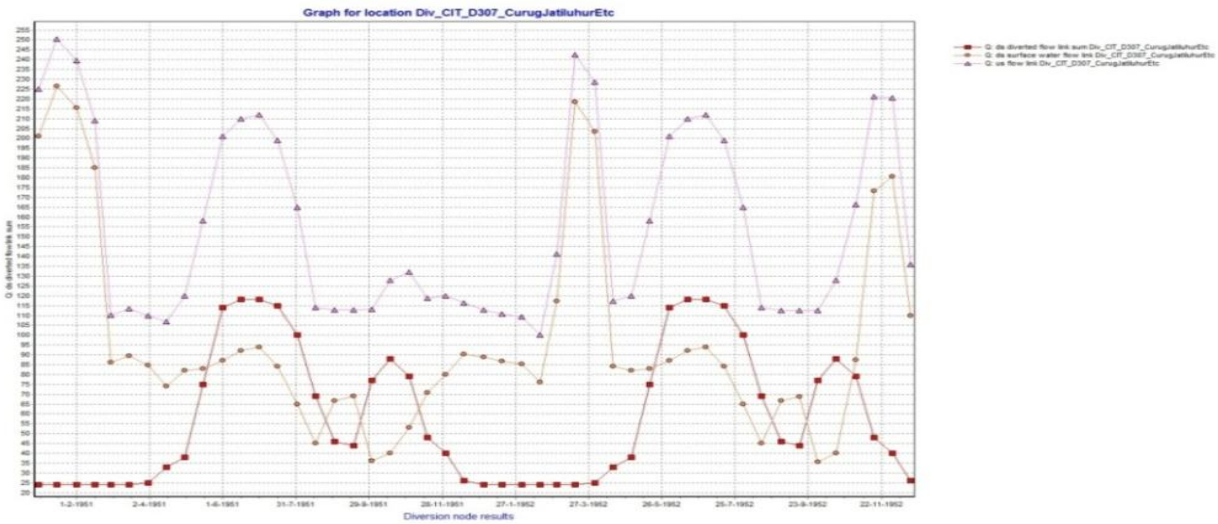



FIGURE 29: CURUG WEIR FLOWS

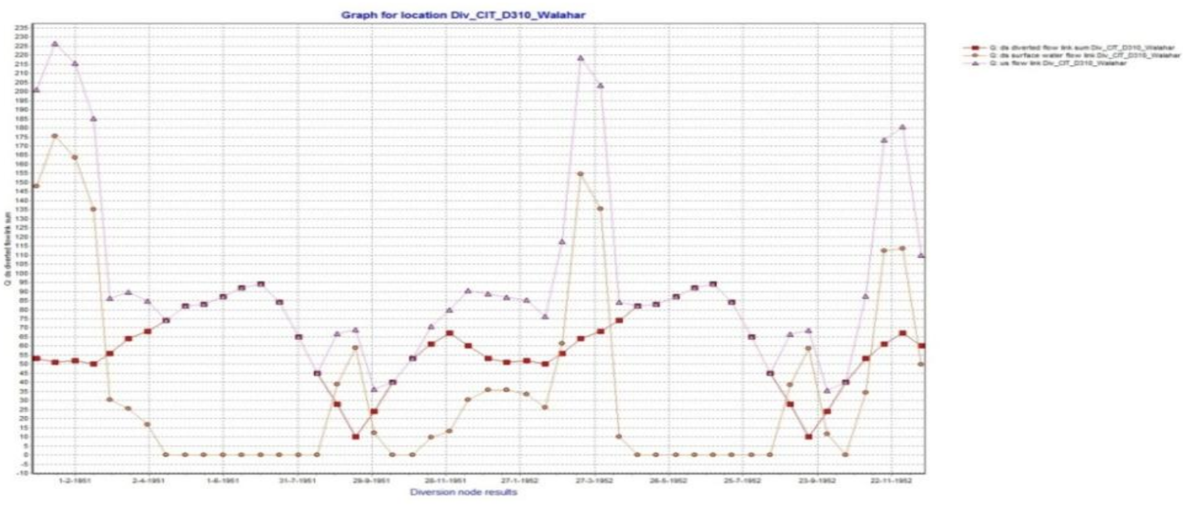



FIGURE 30: WALAHAR WEIR FLOWS

# 5. DISCUSSION

To get an answer on the question whether a water distribution model was needed and feasible in the DSS of PJT II three research questions were defined, these three questions gave answer to the questions: what should the model do?, which components need to be included in the model and do the results provide useful information for PJT II. The choice to first do research on which characteristics such distribution model should was to determine whether RIBASIM satisfies the possibilities that such a water distribution model should have. If RIBASIM did not meet the requirements than no further research should be done. Next it was important to determine which components should be included in the model, it is important to have clarity in what should and what should not be included in the model. By means of answering questions about the purpose of the model the right level of detail was determined that formed a structural basis for designing the model. The third research question was set up to get a conformation whether RIBASIM was indeed suitable as a water distribution model in the DSS of PJT II.

The components that were included in the model were based on the existing 6Cis model and input data from PJT II. The input data for the demand nodes was created by dividing the current water demand in multiple smaller demands. During the set-up of these new demands new calculations had be done to ensure an error margin of 5%, these new calculations lead to slightly different water demands, but the influence of these new calculations was not too drastic in such a way that they will lead to completely different results.

The model includes components of the upstream Citarum River, which were copied from the existing 6Cis model. The frame-work of this research was set on the downstream part of the Citarum River, therefore the input data of the upstream part was not validated, it is assumed that the set-up of the upstream part was done properly. Changes to the upstream part will only affects the model on the supply side of Jatiluhur, and therefore have limit influence on the results.

This study did not focus on the reservoir operation at Jatiluhur. As a result the water outflow of the reservoir was limited, and likely caused shortages that could have been prevented by a different operation of the reservoir. Not to state that all shortages would be prevented because of the multiple variables that determine the water balance, but at least some of them. During a meeting staff members of PJT II stated that the unofficial minimum that they use is 87,5 meters. This is approximately 10 meters lower than the minimum that was found in the first year of the simulations. However, in the dry period of the simulation (1963-1967) the reservoir level did decrease till 90 meters.

The results shown in section 4 are useful for PJT II in a way that the numbers that are being used by the model are not any different from the numbers that are used right now in the decision making process. The numbers are raw and are most likely not the same as the "actual" numbers, but it provides feedback about the effects those policies could have on the water balance. The model operates properly, but it was not possible to validate the results, therefore it is impossible to give an answer on the question whether the results are realistic. However, the results are realistic in such a way that the effects of the water distribution carried out by RIBASIM are realistic, but the magnitude of the effects is most likely different.

# 6. CONLUSION & RECOMMENDATIONS

This report gives an answer on the reconnaissance study on the need and feasibility to integrate a water distribution model in the DSS of PJT II, it simultaneously shows the process on how a water distribution model in RIBASIM has been built for the Citarum river basin, and what kind of possibilities it can provide for the managing organization of that basin: PJT II. At this moment there is no (computer-) model that carries out the water allocation process for PJT II in their decision making process, RIBASIM could be that model in the future.

The characteristics of the water distribution model as needed for PJT II is that it allows policymakers to evaluate different types of policies regarding the water allocation process. RIBASIM visualizes and provides insight in the effects of certain policies and hydrologic scenarios. These effects can be expressed in both water quantity or monetary damages caused by water shortages. A water distribution model calculates the water balance for each time step during a simulation, during each time step a water supply and demand for each (relevant) point of the network is being determined. The balance between water supply, demand and priorities will eventually lead to potential shortages. This gives an answer to the question what the characteristics of a water distribution model were needed for PJT II.

The components that such water distribution model for PJT II should contain are represented in the RIBASIM model. The several rivers, canals and tributaries that should be included in the model because of the level of detail are present. The water distribution model has the same level of detail as is being used by PJT II in their set-up of the water demand. The level of detail is not only determined by the water demand method but also the physical control level that PJT II has over the area. PJT II cannot control all tributaries in the area, and the control level is therefore limited, this is included in the model. The overall water demand that is defined by PJT II is divided into multiple smaller water demands for specific tributaries, which are in line with the determined level of detail, and therefore give answer to the question which components should such model contain for PJT II.

The results that RIBASIM produces in the scenarios that were set-up in this research show the usefulness of RIBASIM for PJT II, because they provide insight into the effects that changes on both the demand and supply side have on the water balance in the Citarum basin. The results help PJT II in determining which areas are most likely to encounter water shortages when changing the conditions. The results in section 4 and appendix G show the changes to the water balance that several scenarios can lead to; this provides PJT II useful information to set up strategies for those scenarios, and this is automatically an answer to the third research question, whether the results produced by the model were useful for PJT II.

The conclusion of this study is that RIBASIM is an added-value for PJT II as an water distribution model in their DSS. The added-value of using RIBASIM is that it simulates the water distribution according to certain policies and scenarios for PJT II. RIBASIM is a simple and easy way for PJT II to evaluate the effects that different scenarios and policies have on the water balance in the Citarum basin. Currently there is no model in the DSS of PJT II that calculates the water balance according to distribution, so it is not urgently needed because the process currently works without a water distribution model, however an implementation of RIBASIM would help PJT II directly, and an implementation of RIBASIM is feasible in the current DSS of PJT II.

It is recommended that in the future still more research need to be done, especially about the upstream reservoirs. Reservoir operation is an important topic for policymakers in water allocation issues. When a good solution has been found for the upstream part of the river, the model will be even more useful and accurate. In a follow-up study it is maybe also good if there is more focus on the supply side of the sub-rivers. In this model the sub-rivers are aggregated to a fixed inflow node, this is a relative simple solution. Also it is maybe a topic for discussion on how the water demand is determined, if the demands get separated more and are given a location, the model can provide even more information.

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# APPENDICES

# APPENDIX A: CURRENT METHOD

PJT II does not have a model to simulate different water allocations. What they do have is a method to calculate the water demand for the river basin. The several water flows are determined based on yearly averages and provided demands of water, electricity and industry companies. In this section will this method be explained, how it is built up, and how it operates. The focus will be on the parts that are relevant for this study. One of the goals of this study is to implement this method into the RIBASIM application.

In the method the Citarum river basin is divided into three regions: West, North and East. This research will only focus on the downstream part from Jatilhur. The three cascade reservoirs (Saguling, Cirata and Jatilhur) are connected in a direct series to each other. From Jatilhur the Citarum flows to Curug, the weir at Curug is responsible for the water distribution into the three separate systems. From Curug the West and East systems are separated from the Citarum. The north system is separated at Walahar weir, further downstream. Therefore it is reasonable to state that water allocation process happens at Curug weir.

The model calculates the water demand for each of those three region-systems. These demands apply for Curug and Walahar weir. Despite the Citarum continuing flowing after Walahar weir, no specific water demand is determined after that. This study will only focus on the part till Walahar weir.

The water demand is estimated on a two weekly base. Every month is divided into two periods of two weeks: I and II. Each year is made up into 12*2=24 time stamps, so each area has 24 separate amounts of water demands. It is not exactly two weeks because that would give 52/2=26 time stamps, but it is roughly. The same time-steps will be used in the model to make sure that there is no conflict regarding inconsistent water demands.

The water demand of each region is built up, from different sub-systems that are connected to each canal. The total water demand of each system is the sum of all sub-systems water demands. The water demand of each sub-system consists out of several components: domestic drink water, agricultural, industrial and electricity. Not every component is applicable on every sub-system, for example the water demand for Jakarta is only based on the domestic drink water need (PJTII, 2012). The demand of the drink water is based on the actually demand that the drink water companies have, this water component also haves the highest priority as stated by (Djajadiredja, 2011).

The largest and second highest priority demand component is the agricultural water demand. The crop is divided into five schedules, each schedule lasts three months. The difference is the start of each schedule, the first one starts in the first week of October, and the fifth one in the first week of December. Basically each time-step a new schedule starts. The crop schedules occur two times a year: the dry and wet season. For each schedule there are two different surfaces, one during the wet- and one for the dry-season. The water demand per hectare for each time-step for each schedule is determined. Therefore, the water demands changes drastically over time. The agricultural water demand is basically the summary of five crop schedules. To calculate the water demand in time-step t for crop schedule y with area x, the formula is as follow:

$$Water\ demand(t)_{y;x} = Area_x * Water\ consumption(t)_y$$

| | Unit |
|---|---|
| Area | Hectare |
| Water consumption | M3/s/hectare |
| Water demand | M3/s |

From this point forward all the units in the water demand method, are m3/s. The area and water consumption are only applicable to the agricultural water demand.

When all the different water demands are determined, the gross water demand is being calculated. This is done by taking the sum of all the individual water demands and multiply it by 0,05. This is an error margin to cover potential losses.

$$Loc_{gross.wat.dem.} = \sum water\ demand * 1.05$$

After the gross water demand is calculated the local water supply will be applied. The local water supply is only applicable to sub-regions that have a upstream part. The local water supply has a negative influence on the water demand, and it is therefore necessary to have an accurate estimation. During the wet periods the influences of the local water supply will probably reduce the water demand of Jatiluhur water in the area, and during the dry season it will be opposite.

$$Loc_{net.wat.dem.} = Loc_{gross.wat.dem.} - Loc_{wat.supply}$$

The total gross water demand of each region is the sum of all the net local water demands.

$$Tot._{gross\ wat.dem.} = \sum Loc_{net.wat.dem.}$$

To calculate the final water demand that will be used in the allocation process, some modifications still have to be done. First of all the total gross water demand will be multiplied again with 5% to create an error margin for unforeseen losses. After adding the 5%, a fixed physical loss will be added (PJTII, 2012). This physical loss is different for each region. In TABLE X, the different physical loss flows are shown.

| | | | |
|---|---|---|---|
| Region | West | North | East |
| Physical loss (m3/s) | 11 | 8 | 9 |

$$Tot._{net.wat.dem} = (Tot._{gross\ wat.dem.} * 1{,}05) + Physical\ loss$$

The total net water demand is the water demand that theoretically based is requested each time-step by the region. This might not be the actual water quantity that is supplied to the area, but gives policymakers an indication about the size of the water demand.

The maximum amount of water that PJT II can supply is based on the canal capacity. It is not possible to supply more water than the water infrastructure is able to. For each of the three regions there is a difference maximum. In appendix B, is shown that the demand for the east system outreaches the capacity of the canal. The difference between what PJT II can supply and what it really supplies is called the water surplus.

| | | | |
|---|---|---|---|
| Region | West | North | East |
| Maximum supply (m3/s) | 57,5 | 95 | 62,5 |

$$Water\ Surplus = Maximum\ possible\ supply - Actual\ water\ supply$$

A low water surplus indicates that the water supply is already close to the maximum capacity. In a case of a low surplus action could be taken in two ways, try to reduce the water demand but that is not likely to happen, or enlarge the capacity of the canals.

The recommendation that the system gives to the policymakers is the minimum amount of water that is demanded. The recommendation is just a guideline for the policymakers, because the situation in reality is always different then the theoretically based situation in the model. The weather at the moment of deciding is the big key, because it is hard to estimate what the weather will do on a two week base for the rest of the year. If it is dryer or wetter than expected the outflow of Jatiluhur will be adjusted to situation at that moment. This largely due to the fact that estimations are made one time a year, so it is based on historical data, and deviations are always occurring.

For quick analyses PJT II has a water demand for the whole area that will be distracted directly from the Jatiluhur reservoir. In Figure 31 the water demands for the whole river basin are stated. Basically, this water demand is the summary of the three different region demands. The demand line shows some clear trends, during the dry period the demand increases, and decreases in the wet period. This is likely to be caused by the change in local water supply during the dry and wet season. Another highlight that stood out is the low demand in the month of September. In the creation of the water demand of the farmers, there is no crop planned in September. This is done in order to create a buffer for possible maintenance and evaluate and re-drafting the water demand for the next year (PJTII, 2012). In reality farmers usually keep farming, unless the danger of potential water shortage.

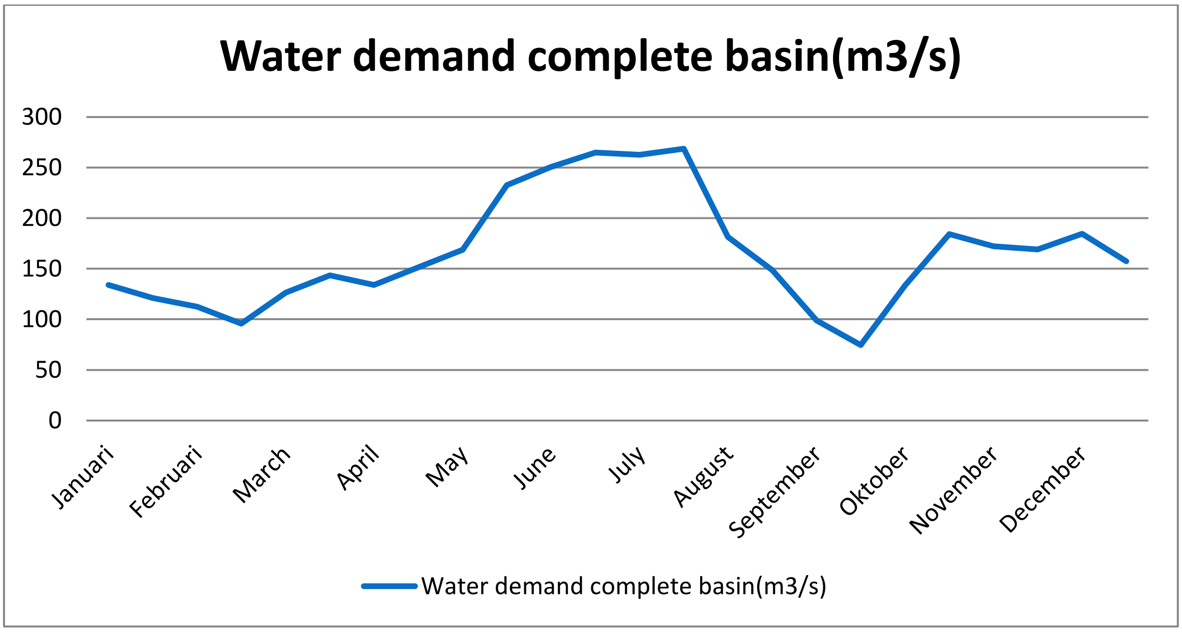



FIGURE 31: TOTAL WATER DEMAND THREE SYSTEMS

West

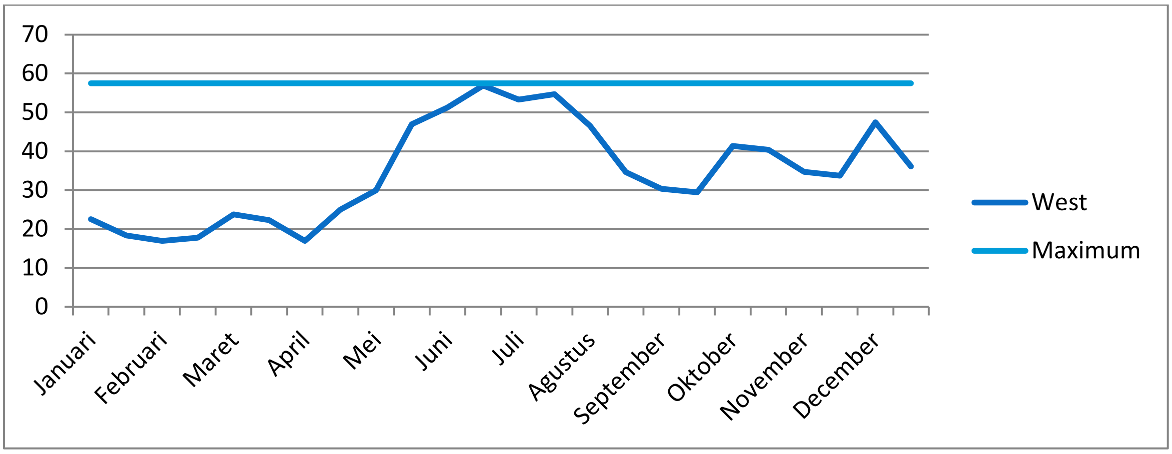



FIGURE 32: WEST WATER DEMAND VS. CAPACITY

North

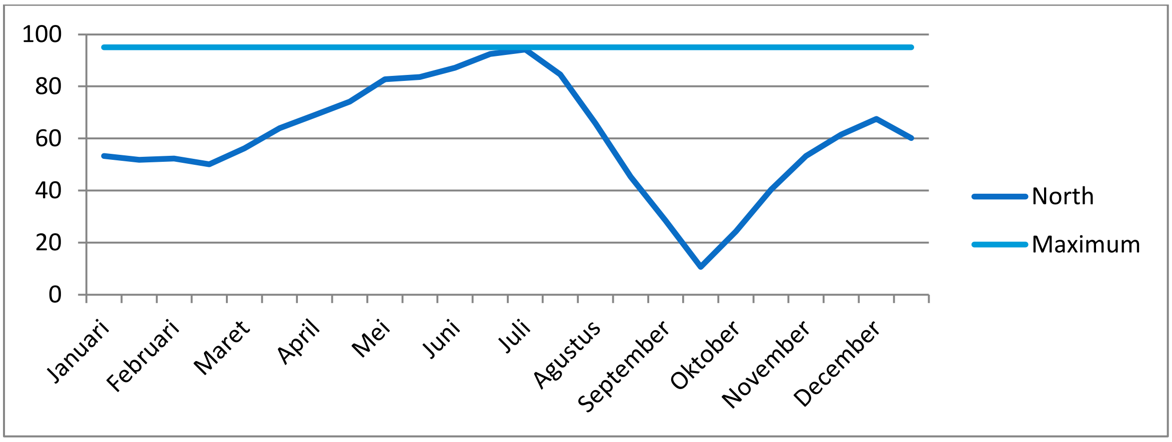



FIGURE 33: NORTH WATER DEMAND VS. CAPACITY

East

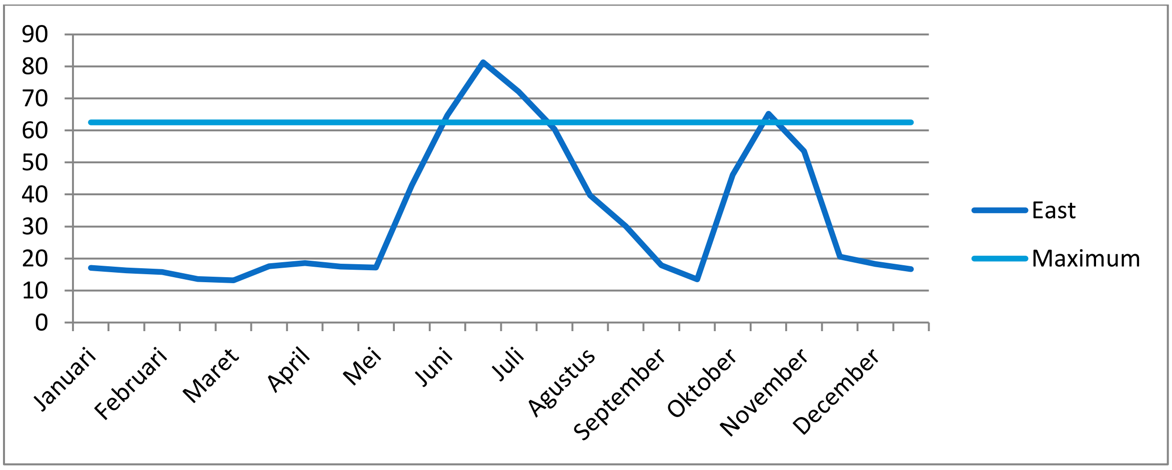



FIGURE 34: EAST WATER DEMAND VS. CAPACITY

Full Network:

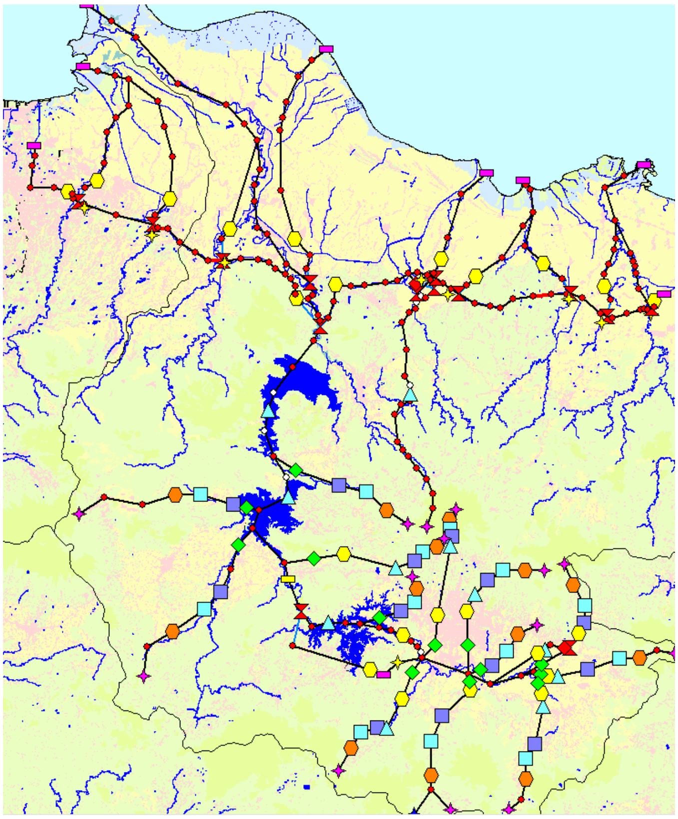


FIGURE 35: FULL RIBASIM NETWORK

West system:

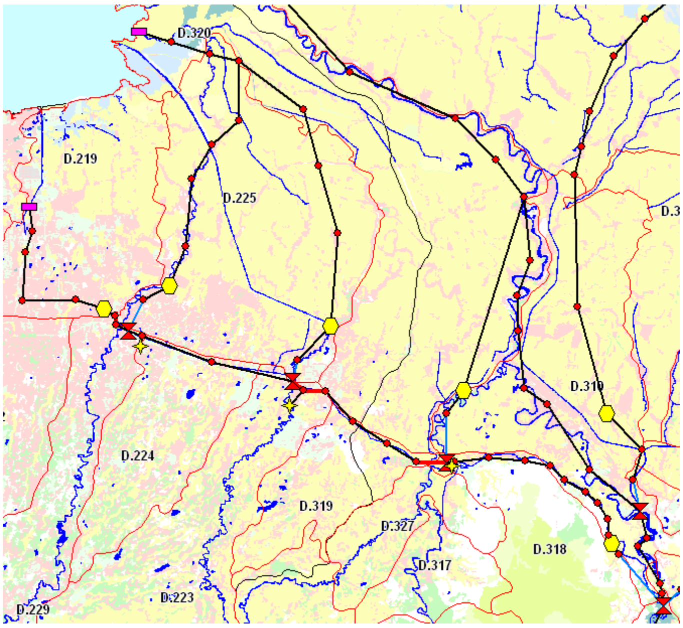



FIGURE 36: WEST SYSTEM NETWORK

North system:

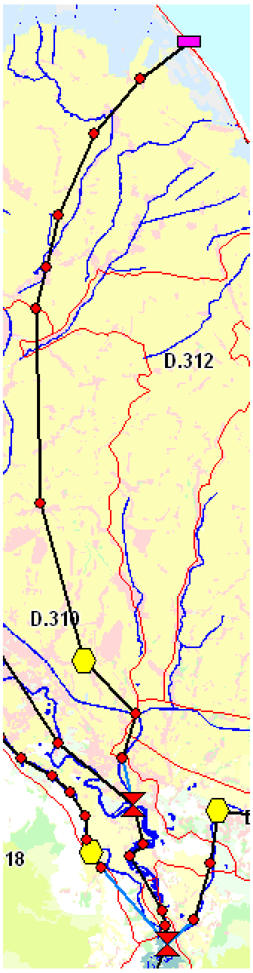



FIGURE 37: NORTH SYSTEM RIBASIM

East system:

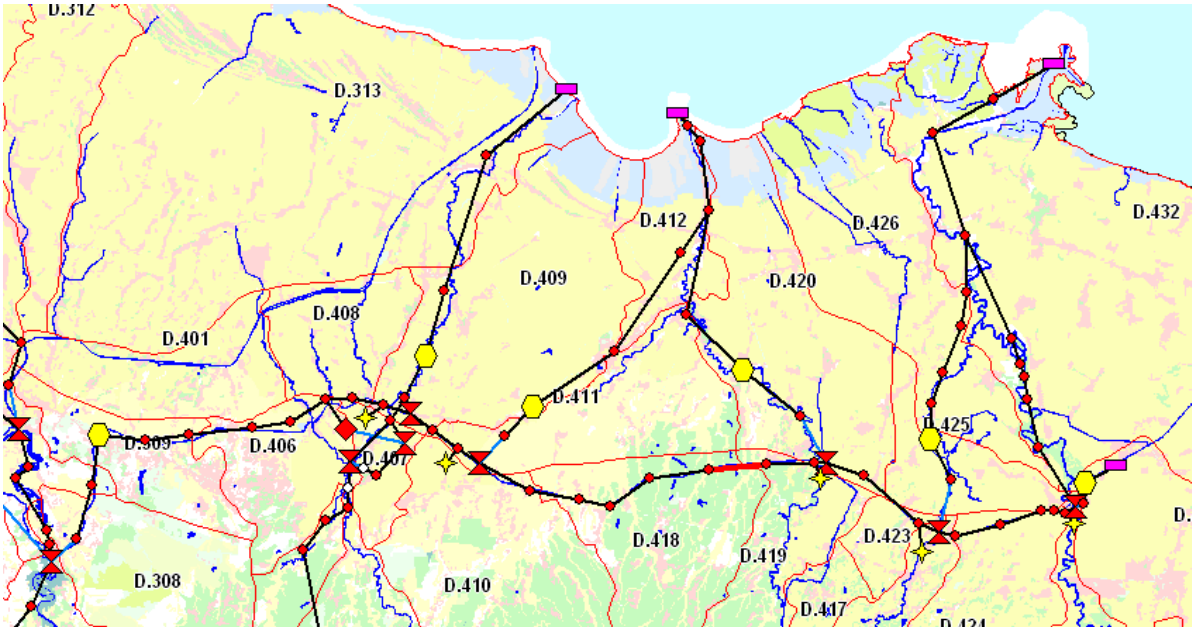



FIGURE 38: EAST SYSTEM RIBASIM

## APPENDIX D: SUPPLY-, DEMAND INPUT DATA

The input data for the several inflow and demand nodes are shown in this section. The demand input data does not change in the several scenarios, therefore the demand data is shown independent of the scenarios.

Demand:

TABLE 7: DEMAND PER NODE

| Water demand ($m^3/s$) | | West | | | | | | East | | | | | | | North |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jakarta | Bekasi | Cikarang | Cibeet | Start | Total | Salamdarma | Gadung | Macan | Jengkol | Barugbug | Start | Total | Walahar |
| January | I | 16 | 3 | 11 | 11 | 13 | 54 | 22 | 5 | 9 | 2 | 9 | 11 | 59 | 53 |
| | II | 16 | 3 | 10 | 11 | 13 | 53 | 21 | 5 | 9 | 2 | 9 | 11 | 57 | 52 |
| February | I | 16 | 3 | 11 | 10 | 13 | 53 | 20 | 4 | 8 | 2 | 9 | 11 | 55 | 52 |
| | II | 16 | 3 | 11 | 8 | 13 | 51 | 18 | 3 | 4 | 2 | 8 | 11 | 46 | 50 |
| March | I | 16 | 3 | 10 | 11 | 13 | 53 | 16 | 4 | 8 | 1 | 6 | 11 | 46 | 56 |
| | II | 16 | 3 | 8 | 11 | 13 | 51 | 20 | 4 | 10 | 1 | 7 | 11 | 54 | 64 |
| April | I | 16 | 2 | 8 | 13 | 13 | 53 | 22 | 4 | 11 | 2 | 12 | 12 | 63 | 69 |
| | II | 16 | 3 | 17 | 15 | 14 | 64 | 21 | 6 | 10 | 3 | 13 | 12 | 65 | 74 |
| May | I | 16 | 4 | 18 | 15 | 14 | 67 | 28 | 6 | 11 | 3 | 12 | 12 | 71 | 83 |
| | II | 16 | 4 | 17 | 16 | 14 | 66 | 29 | 6 | 22 | 3 | 12 | 13 | 85 | 84 |
| June | I | 16 | 4 | 17 | 17 | 14 | 67 | 31 | 7 | 38 | 3 | 14 | 14 | 106 | 87 |
| | II | 16 | 4 | 19 | 16 | 14 | 68 | 34 | 8 | 49 | 3 | 16 | 15 | 125 | 92 |
| July | I | 16 | 4 | 19 | 13 | 14 | 66 | 34 | 7 | 40 | 4 | 17 | 14 | 117 | 94 |
| | II | 16 | 4 | 18 | 10 | 13 | 61 | 28 | 6 | 38 | 3 | 13 | 13 | 100 | 85 |
| August | I | 16 | 3 | 12 | 4 | 13 | 48 | 20 | 3 | 23 | 1 | 6 | 12 | 65 | 66 |
| | II | 16 | 1 | 3 | 2 | 12 | 35 | 14 | 0 | 16 | 0 | 2 | 11 | 43 | 45 |
| September | I | 16 | 1 | 2 | 2 | 12 | 32 | 4 | 0 | 4 | 0 | 2 | 10 | 20 | 29 |
| | II | 16 | 1 | 2 | 2 | 12 | 32 | 2 | 0 | 2 | 0 | 1 | 9 | 15 | 11 |
| Oktober | I | 16 | 1 | 3 | 10 | 13 | 42 | 11 | 11 | 9 | 0 | 2 | 11 | 44 | 24 |
| | II | 16 | 1 | 2 | 10 | 12 | 41 | 17 | 7 | 36 | 1 | 8 | 13 | 82 | 40 |
| November | I | 16 | 1 | 8 | 14 | 13 | 52 | 23 | 6 | 28 | 3 | 15 | 13 | 87 | 53 |
| | II | 16 | 3 | 17 | 15 | 14 | 66 | 25 | 8 | 12 | 3 | 15 | 12 | 75 | 62 |
| December | I | 16 | 5 | 17 | 14 | 14 | 66 | 29 | 6 | 11 | 3 | 12 | 12 | 73 | 67 |
| | II | 16 | 4 | 13 | 12 | 13 | 59 | 26 | 5 | 10 | 2 | 10 | 12 | 65 | 60 |

Supply:

"Base-Case"

TABLE 8: SUPPLY PER NODE BASE CASE

| Water supply (m3/s) | | West | | | | East | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Bekasi | Cikarang | Cibeet | Total: | Salamdarma | Gadung | Macan | Jengkol | Barugbug | Total: |
| Januari | I | 17 | 6 | 23 | 46 | 35 | 7 | 8 | 14 | 11 | 74 |
| | II | 17 | 7 | 30 | 54 | 38 | 5 | 9 | 20 | 14 | 86 |
| Februari | I | 19 | 8 | 31 | 58 | 57 | 10 | 9 | 26 | 33 | 136 |
| | II | 20 | 9 | 35 | 64 | 53 | 12 | 9 | 19 | 36 | 128 |
| Maret | I | 23 | 11 | 24 | 58 | 53 | 9 | 10 | 16 | 23 | 111 |
| | II | 22 | 12 | 23 | 56 | 74 | 9 | 11 | 19 | 21 | 133 |
| April | I | 20 | 10 | 21 | 50 | 66 | 6 | 19 | 14 | 27 | 132 |
| | II | 19 | 8 | 17 | 45 | 53 | 11 | 17 | 18 | 21 | 121 |
| Mei | I | 18 | 8 | 15 | 41 | 34 | 7 | 11 | 14 | 15 | 81 |
| | II | 17 | 4 | 12 | 32 | 20 | 5 | 4 | 8 | 7 | 46 |
| Juni | I | 8 | 3 | 5 | 17 | 10 | 4 | 3 | 6 | 8 | 31 |
| | II | 6 | 2 | 5 | 14 | 7 | 2 | 3 | 5 | 7 | 23 |
| Juli | I | 4 | 2 | 4 | 10 | 6 | 3 | 2 | 3 | 7 | 21 |
| | II | 4 | 1 | 3 | 8 | 1 | 1 | 1 | 3 | 5 | 12 |
| Agustus | I | 4 | 1 | 1 | 6 | 1 | 1 | 1 | 2 | 2 | 7 |
| | II | 2 | 1 | 1 | 4 | 0 | 1 | 1 | 1 | 1 | 3 |
| September | I | 2 | 0 | 1 | 3 | 1 | 1 | 1 | 1 | 0 | 4 |
| | II | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 2 |
| Oktober | I | 3 | 1 | 1 | 4 | 2 | 1 | 1 | 1 | 0 | 5 |
| | II | 5 | 1 | 9 | 15 | 1 | 1 | 1 | 1 | 3 | 6 |
| November | I | 8 | 2 | 13 | 22 | 10 | 7 | 2 | 7 | 12 | 37 |
| | II | 12 | 3 | 14 | 29 | 32 | 8 | 6 | 8 | 20 | 74 |
| December | I | 13 | 3 | 22 | 38 | 32 | 9 | 6 | 9 | 16 | 71 |
| | II | 16 | 6 | 22 | 44 | 35 | 9 | 7 | 9 | 16 | 75 |

## "Base-Case-10%"

TABLE 9: SUPPLY BASE CASE -10%

| | | -10% | West | | | | East | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bekasi | Cikarang | Cibeet | Total: | Salamdarma | Gadung | Macan | Jengkol | Barugbug | Total |
| Water supply (m3/s) | Januari | I | 15 | 6 | 20 | 41 | 31 | 6 | 7 | 12 | 10 | 67 |
| | | II | 15 | 6 | 27 | 49 | 34 | 5 | 8 | 18 | 13 | 77 |
| | Februari | I | 17 | 8 | 27 | 52 | 51 | 9 | 8 | 23 | 30 | 122 |
| | | II | 18 | 8 | 32 | 58 | 47 | 11 | 8 | 17 | 32 | 115 |
| | Maret | I | 20 | 10 | 22 | 53 | 48 | 8 | 9 | 14 | 21 | 100 |
| | | II | 20 | 11 | 20 | 51 | 66 | 8 | 10 | 17 | 19 | 120 |
| | April | I | 18 | 9 | 18 | 45 | 59 | 5 | 17 | 13 | 24 | 119 |
| | | II | 17 | 8 | 16 | 40 | 48 | 10 | 16 | 17 | 19 | 109 |
| | Mei | I | 16 | 7 | 14 | 37 | 30 | 6 | 10 | 13 | 14 | 73 |
| | | II | 15 | 3 | 11 | 29 | 18 | 5 | 4 | 7 | 7 | 41 |
| | Juni | I | 8 | 3 | 5 | 15 | 9 | 4 | 3 | 5 | 7 | 28 |
| | | II | 6 | 2 | 4 | 12 | 6 | 2 | 3 | 4 | 6 | 21 |
| | Juli | I | 4 | 2 | 4 | 9 | 6 | 3 | 2 | 3 | 6 | 19 |
| | | II | 3 | 1 | 3 | 7 | 1 | 1 | 1 | 3 | 4 | 11 |
| | Agustus | I | 3 | 1 | 1 | 5 | 1 | 1 | 1 | 1 | 2 | 7 |
| | | II | 2 | 0 | 1 | 4 | 0 | 0 | 1 | 1 | 0 | 3 |
| | September | I | 2 | 0 | 1 | 2 | 1 | 1 | 1 | 1 | 0 | 3 |
| | | II | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 2 |
| | Oktober | I | 2 | 1 | 1 | 3 | 2 | 1 | 1 | 1 | 0 | 5 |
| | | II | 4 | 1 | 8 | 13 | 1 | 1 | 1 | 1 | 2 | 6 |
| | November | I | 7 | 2 | 11 | 20 | 9 | 6 | 2 | 6 | 11 | 34 |
| | | II | 11 | 3 | 13 | 26 | 29 | 7 | 5 | 7 | 18 | 66 |
| | December | I | 11 | 3 | 20 | 34 | 28 | 8 | 6 | 8 | 14 | 64 |
| | | II | 14 | 5 | 20 | 39 | 31 | 8 | 7 | 8 | 14 | 68 |

## "Base-Case+10%"

TABLE 10: SUPPLY BASE CASE +10%

| | | 10% | West | | | | East | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bekasi | Cikarang | Cibeet | Total | Salamdarma | Gadung | Macan | Jengkol | Barugbug | Total |
| Water supply (m3/s) | Januari | I | 19 | 7 | 25 | 51 | 38 | 8 | 8 | 15 | 12 | 81 |
| | | II | 19 | 7 | 33 | 59 | 41 | 6 | 10 | 22 | 15 | 95 |
| | Februari | I | 21 | 9 | 34 | 63 | 63 | 11 | 10 | 28 | 36 | 149 |
| | | II | 22 | 10 | 39 | 71 | 58 | 13 | 10 | 20 | 39 | 141 |
| | Maret | I | 25 | 12 | 27 | 64 | 59 | 10 | 11 | 17 | 25 | 123 |
| | | II | 24 | 13 | 25 | 62 | 81 | 10 | 12 | 21 | 23 | 146 |
| | April | I | 22 | 11 | 23 | 55 | 72 | 6 | 21 | 15 | 30 | 145 |
| | | II | 21 | 9 | 19 | 49 | 58 | 12 | 19 | 20 | 23 | 133 |
| | Mei | I | 20 | 8 | 17 | 45 | 37 | 7 | 12 | 16 | 17 | 89 |
| | | II | 18 | 4 | 13 | 35 | 22 | 6 | 5 | 9 | 8 | 50 |
| | Juni | I | 9 | 3 | 6 | 19 | 11 | 4 | 3 | 6 | 9 | 34 |
| | | II | 7 | 3 | 5 | 15 | 7 | 2 | 4 | 5 | 7 | 26 |
| | Juli | I | 5 | 2 | 4 | 11 | 7 | 4 | 2 | 4 | 8 | 24 |
| | | II | 4 | 1 | 3 | 9 | 1 | 2 | 1 | 3 | 5 | 13 |
| | Agustus | I | 4 | 1 | 2 | 7 | 1 | 2 | 1 | 2 | 3 | 8 |
| | | II | 2 | 1 | 1 | 4 | 0 | 1 | 1 | 1 | 1 | 4 |
| | Septembe | I | 2 | 0 | 1 | 3 | 1 | 1 | 1 | 1 | 0 | 4 |
| | | II | 1 | 1 | 0 | 2 | 0 | 0 | 1 | 1 | 0 | 2 |
| | Oktober | I | 3 | 1 | 1 | 4 | 3 | 1 | 1 | 1 | 0 | 6 |
| | | II | 5 | 1 | 10 | 16 | 1 | 1 | 1 | 1 | 3 | 7 |
| | November | I | 9 | 2 | 14 | 25 | 11 | 8 | 2 | 8 | 13 | 41 |
| | | II | 13 | 3 | 16 | 32 | 35 | 9 | 6 | 9 | 22 | 81 |
| | December | I | 14 | 4 | 24 | 42 | 35 | 9 | 7 | 9 | 17 | 78 |
| | | II | 17 | 6 | 25 | 48 | 38 | 9 | 8 | 9 | 17 | 83 |

# APPENDIX E: DIMENSIONS NODES MODEL

## Overview:

Table 1.1. Dimension of the present schematization

| Description of network elements | Total | Active | Inactive |
|---|---|---|---|
| Number of nodes | 298 | 274 | 24 |
| Number of water allocation priorities | 4 | | |
| Number of variable inflow nodes | 15 | 14 | 1 |
| Number of fixed inflow nodes | 9 | 9 | 0 |
| Number of confluence nodes | 154 | 154 | 0 |
| Number of recording nodes | 8 | 8 | 0 |
| Number of terminal nodes | 9 | 9 | 0 |
| Number of surface water reservoir nodes | 11 | 3 | 8 |
| Number of run-of-river nodes | 1 | 1 | 0 |
| Number of diversion nodes | 14 | 14 | 0 |
| Number of low flow nodes | 15 | 1 | 14 |
| Number of public water supply nodes | 36 | 35 | 1 |
| Number of advanced irrigation nodes | 26 | 26 | 0 |
| Number of links | 305 | 305 | 0 |
| Number of surface water flow link | 290 | 290 | 0 |
| Number of diverted flow link | 15 | 15 | 0 |

## Timesteps:

Table 1.2. Simulation time step definition data

Max. number of timesteps in one year (first time step starts 1 january) : 24

| Time step Ix | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Length (days) | 15 | 16 | 15 | 13 | 15 | 16 | 15 | 15 | 15 | 16 | 15 | 15 | 15 | 16 | 15 | 16 | 15 | 15 | 15 | 16 | 15 | 15 | 15 | 16 |
| Leap year days | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPENDIX F: CANAL CAPACITY EAST & WEST

The canal capacity is determined using Figure 39 and Table 11. Figure 39 shows the nodes that represents river tributaries. In Table 11, the capacity for node stretches are shown, the capacities for these stretches are copied to the RIBASIM model.

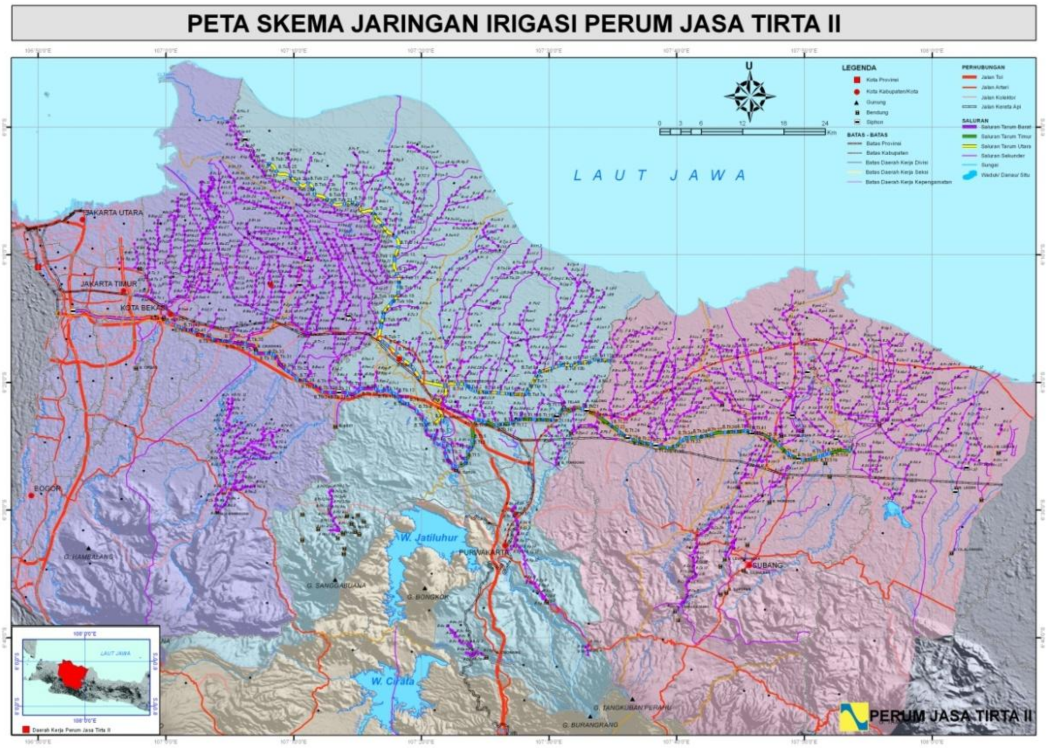



FIGURE 39: NODES LISTED AT PJT II

TABLE 11: CAPACITY PER NODE

| Main Canal Section Tarum West | | Main Canal Section Tarum East | |
|---|---|---|---|
| CANAL | CAPACITY_Q (M3/S) | CANAL | CAPACITY_Q (M3/S) |
| Curug Weir - B. Tb 5 | 82 | Curug Weir - B. Tt 8 | 83,88 |
| B. Tb 5 - B. Tb 17 | 80 | B. Tt 8 - B. Tt 16 | 77,98 |
| B. Tb 17 - B. Tb 20 | 76,1 | B. Tt 16 - B. Tt 20 | 71,1 |
| B. Tb 20 - B. Tb 21 | 72,5 | B. Tt 22 - B. Tt 28 | 55,857 |
| B. Tb 21 - B. Tb 22 | 69,3 | B. Tt 29 - B. Tt 31 | 55,04 |
| B. Tb 22 - B. Tb 23 | 80,1 | B. Tt 31 - B. Tt 40a | 52,03 |
| B. Tb 23 - B. Tb 26 | 56,1 | B. Tt 40a - B. Tt 44 | 42,03 |
| B. Tb 28 - B. Tb 32 | 53,9 | B. Tt 45 - B. Tt 51 | 43,776 |
| B. Tb 32 - B. Tb 33 | 49,3 | B. Tt 51 - B. Tt 53a | 31 |
| B. Tb 33 - B. Tb 34 | 48,8 | | |
| B. Tb 34 - B. Tb 35 | 39,3 | | |
| B. Tb 35 - B. Tb 40 | 34,6 | | |
| B. Tb 40 - B. Tb 43 | 32 | | |
| B. Tb 43 - B. Tb 44 | 31,3 | | |

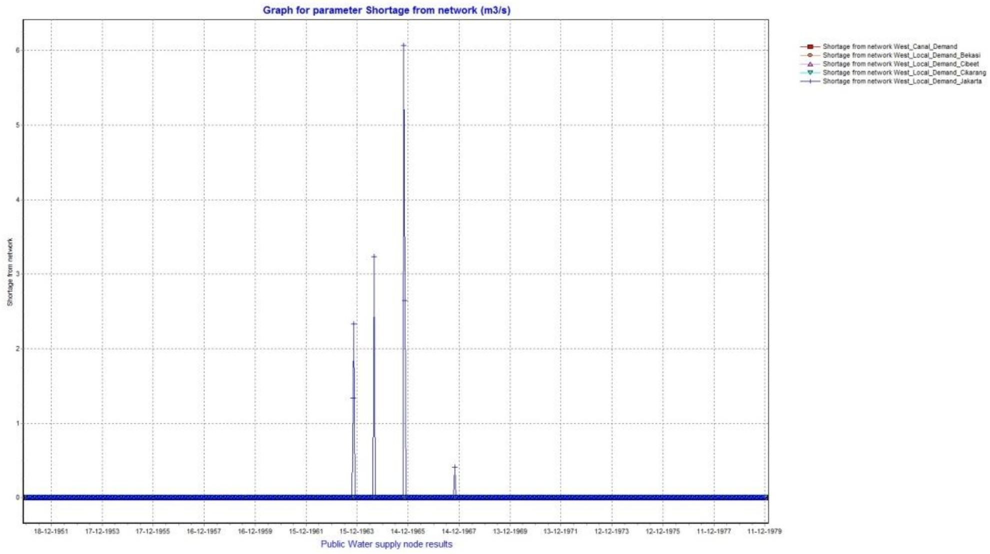
# APPENDIX G: SCENARIOS RESULTS

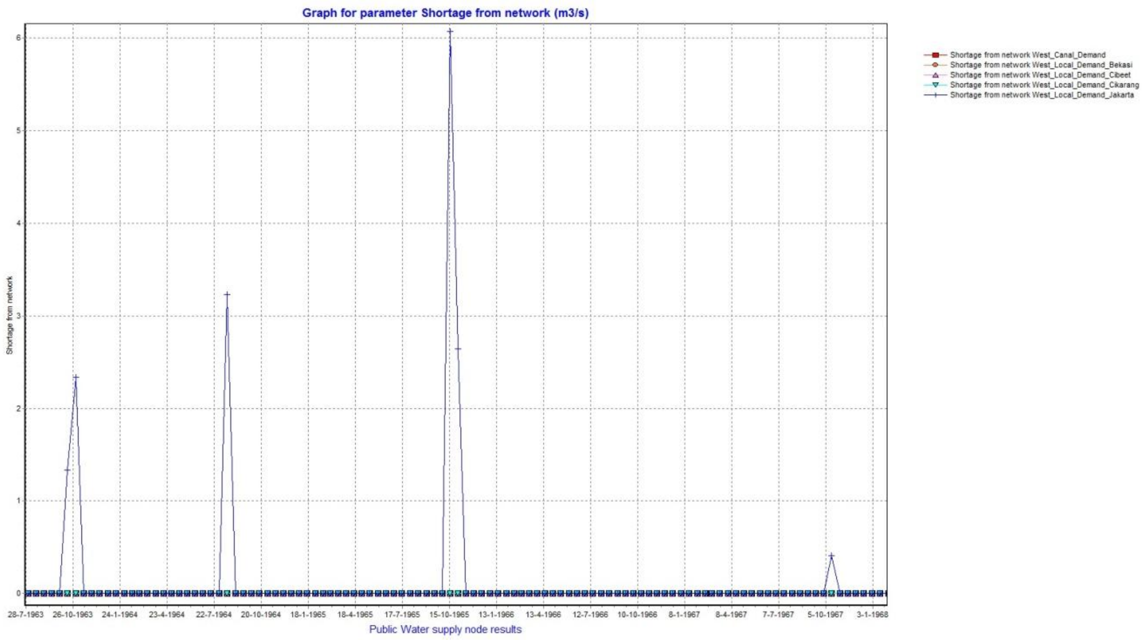
Four scenarios are generated to show examples of information that could help policymakers in their planning of water resources management. The results of the “Base-Case” are already shown in section 4; the remaining three scenarios are shown in this section. To compare the results, the same model outputs are displayed: water shortage, reservoir behavior and weir flows.

## G.1. “BASE CASE-10%INFLOW”

In this case the local inflow in the canals is reduced with 10%; the demands are equal to the base case. In appendix d, the reduced inflows are shown per inflow point. It is likely that new water shortages will occur because of the decreasing inflow.

**West System:**



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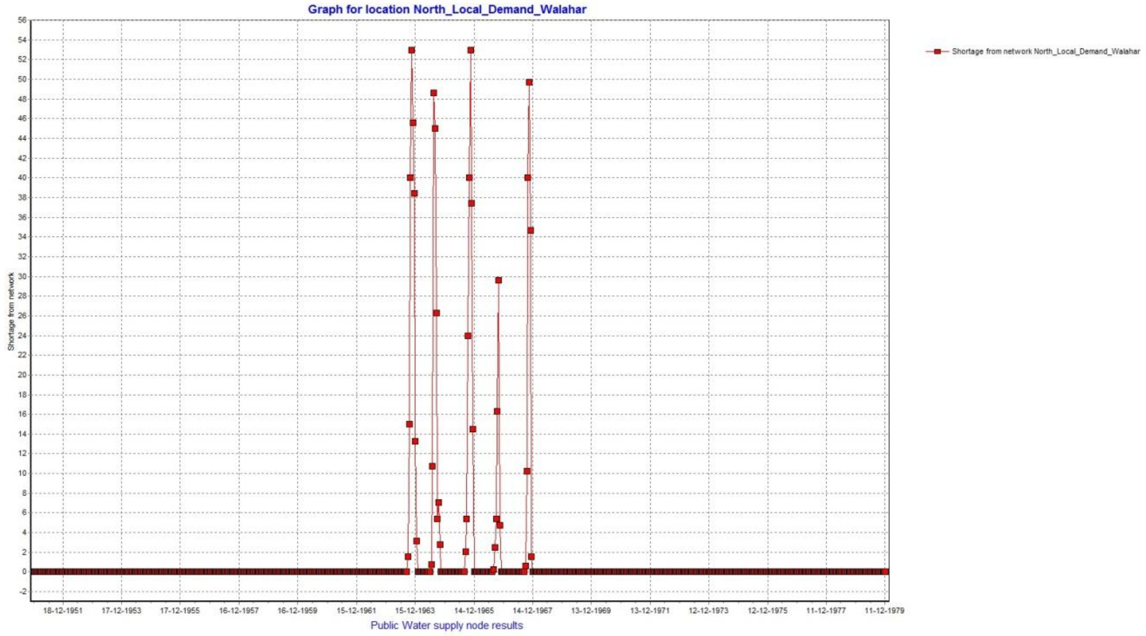
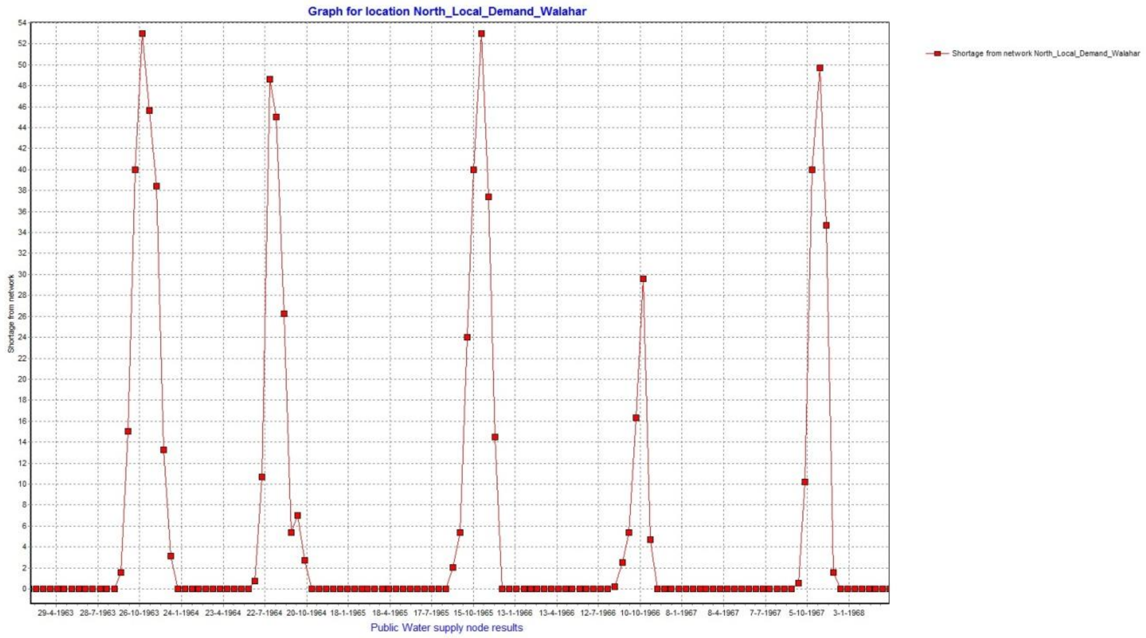
**North System**



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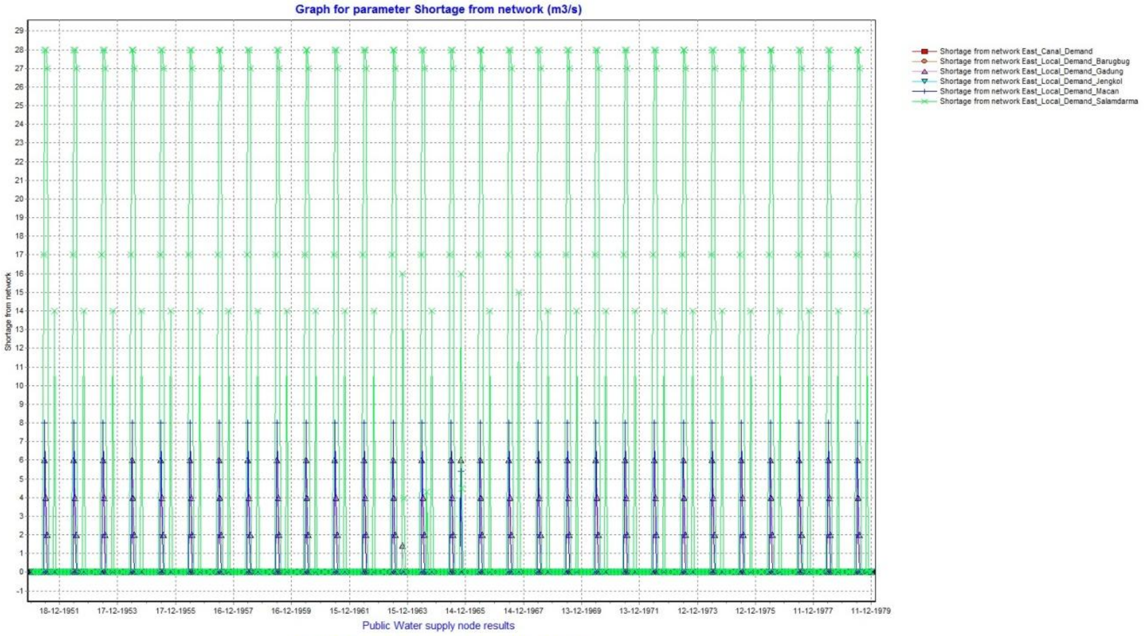
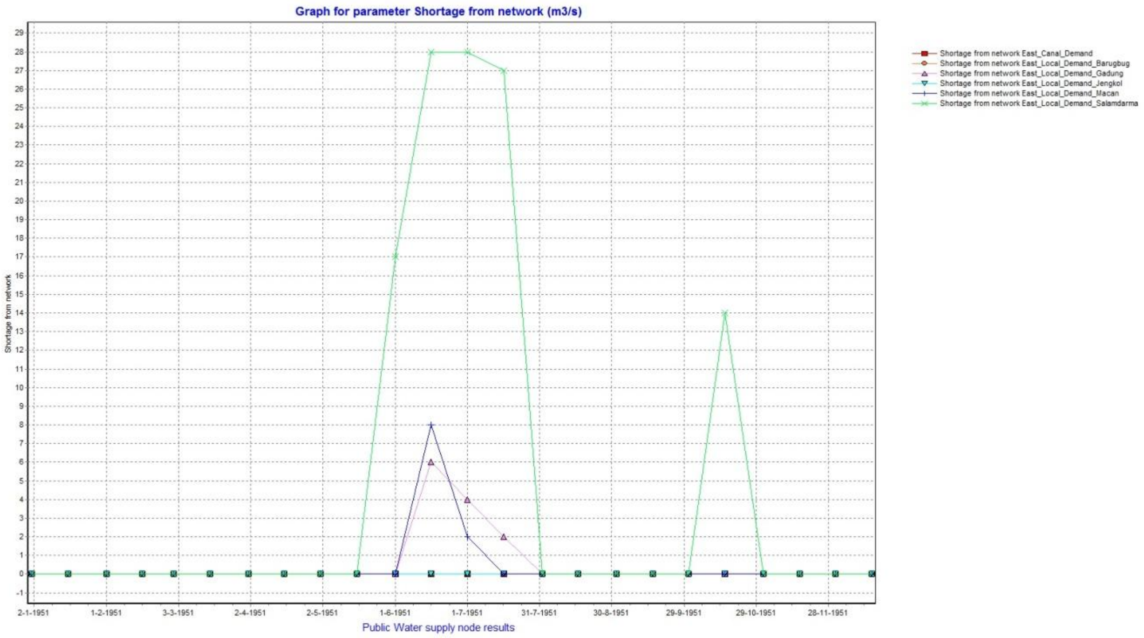
## East System



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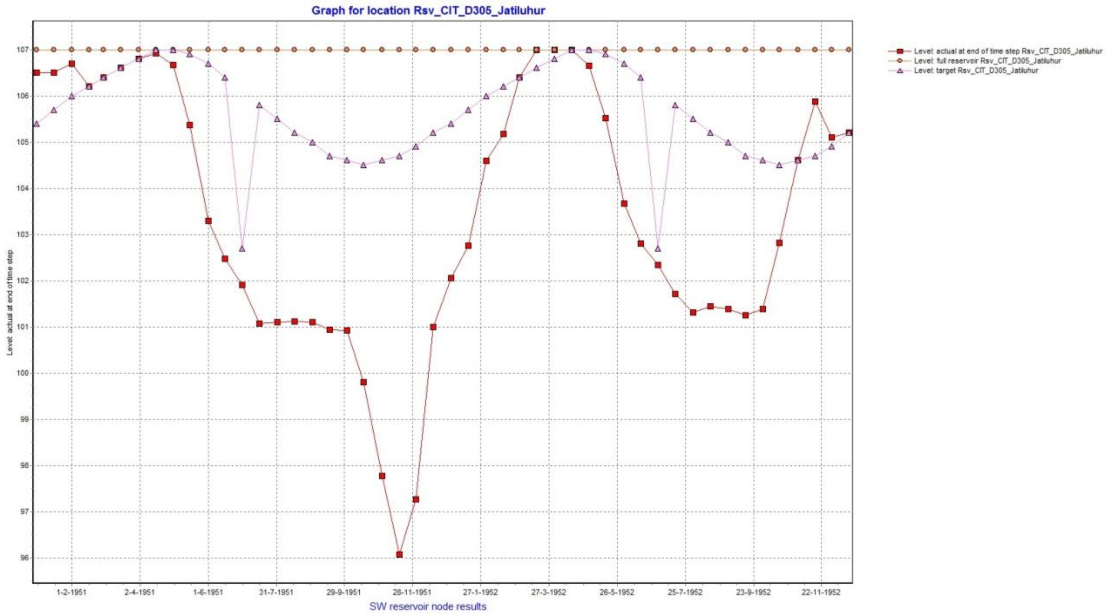
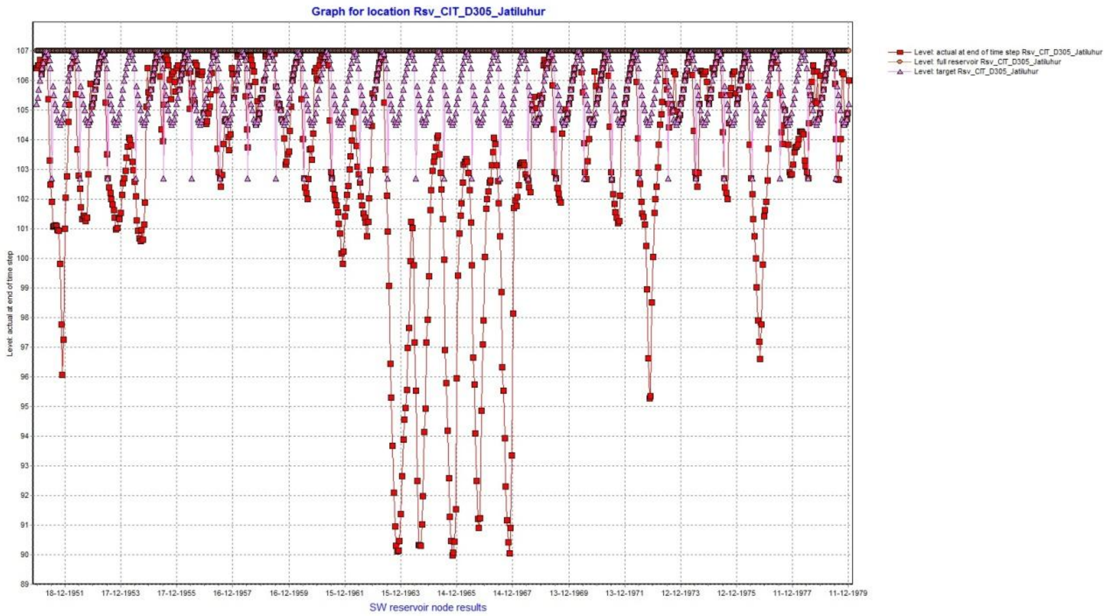
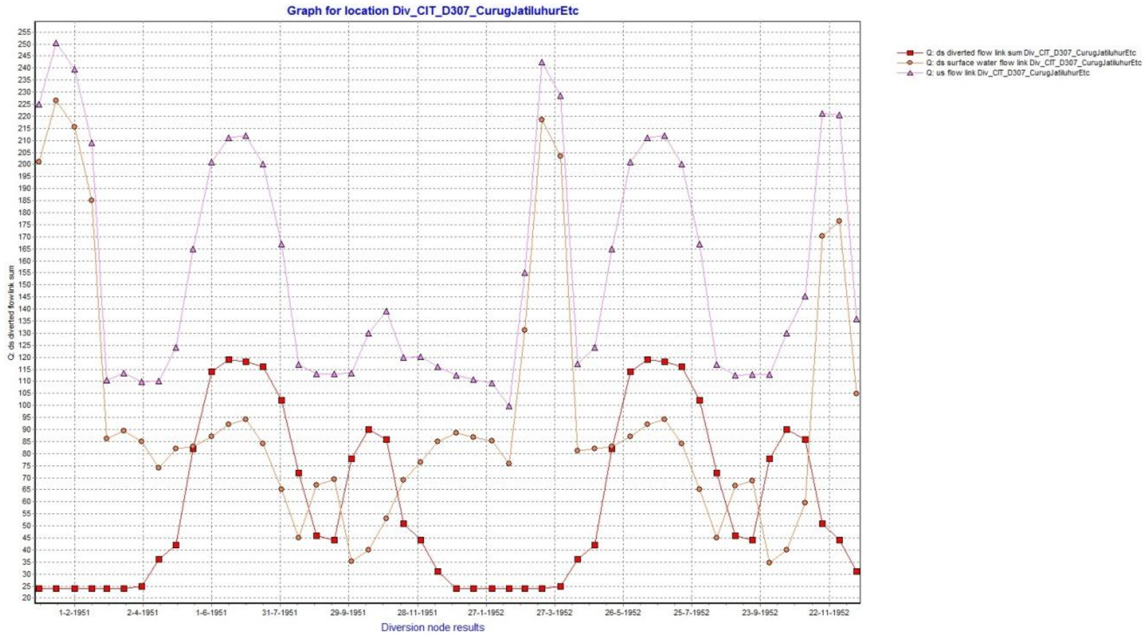
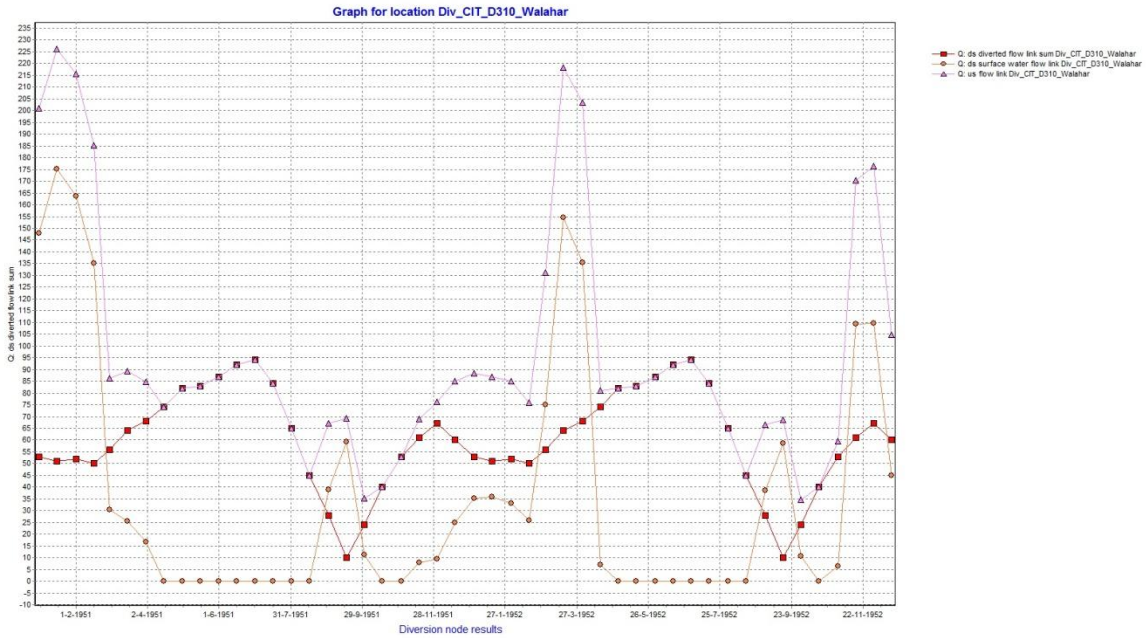
## Jatiluhur reservoir



## Walahar & Curug Weirs



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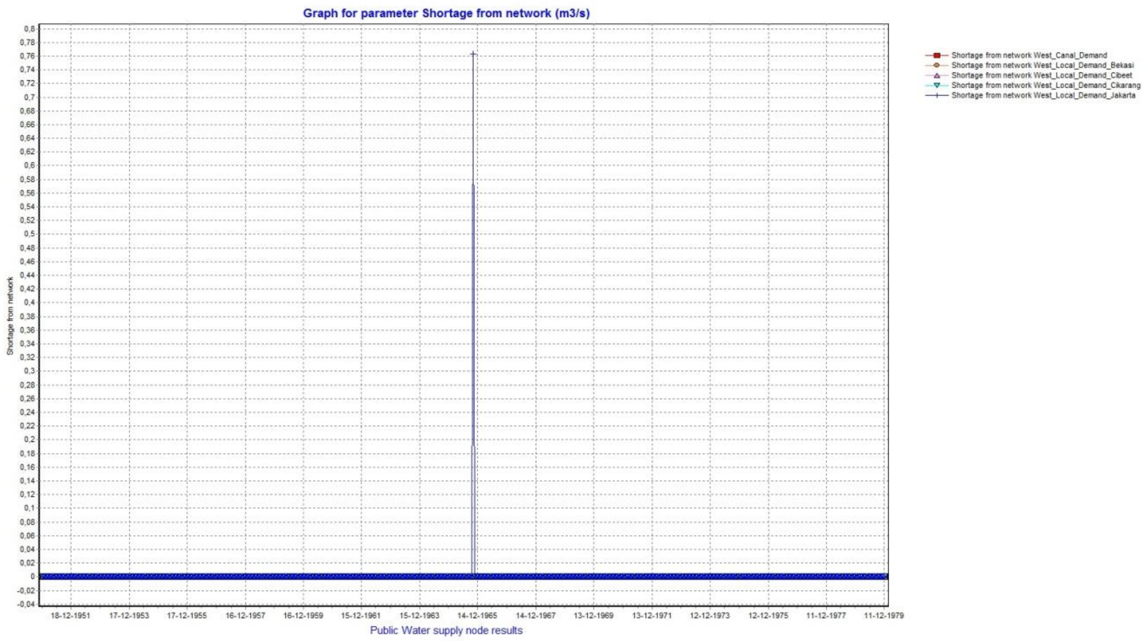
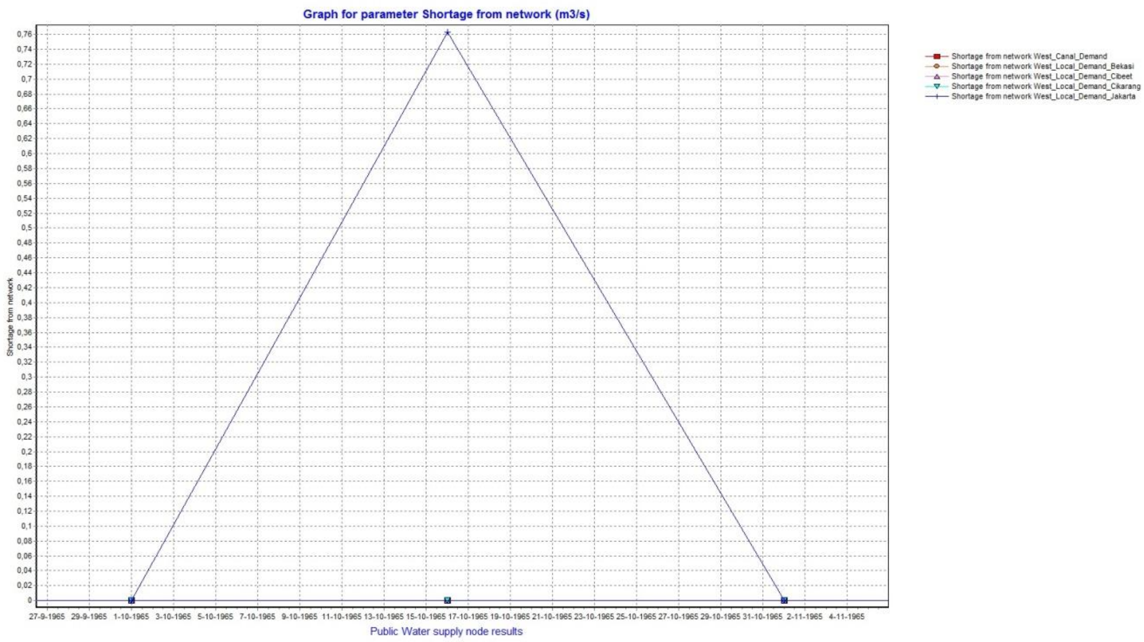
## G.2. “BASE CASE+10%INFLOW”

The local fixed inflow in this case is increased with 10%. The fixed inflow is shown in Table 10 in appendix D. With a higher inflow, it is reasonable to expect that the water shortage will decrease because of the higher water supply.

**West System**



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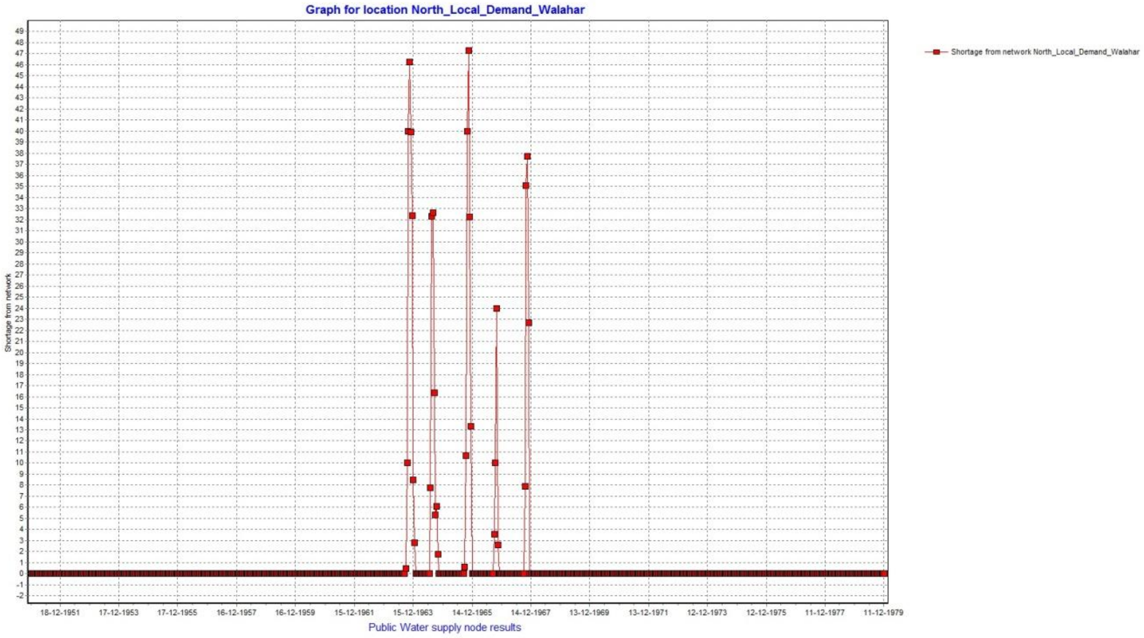
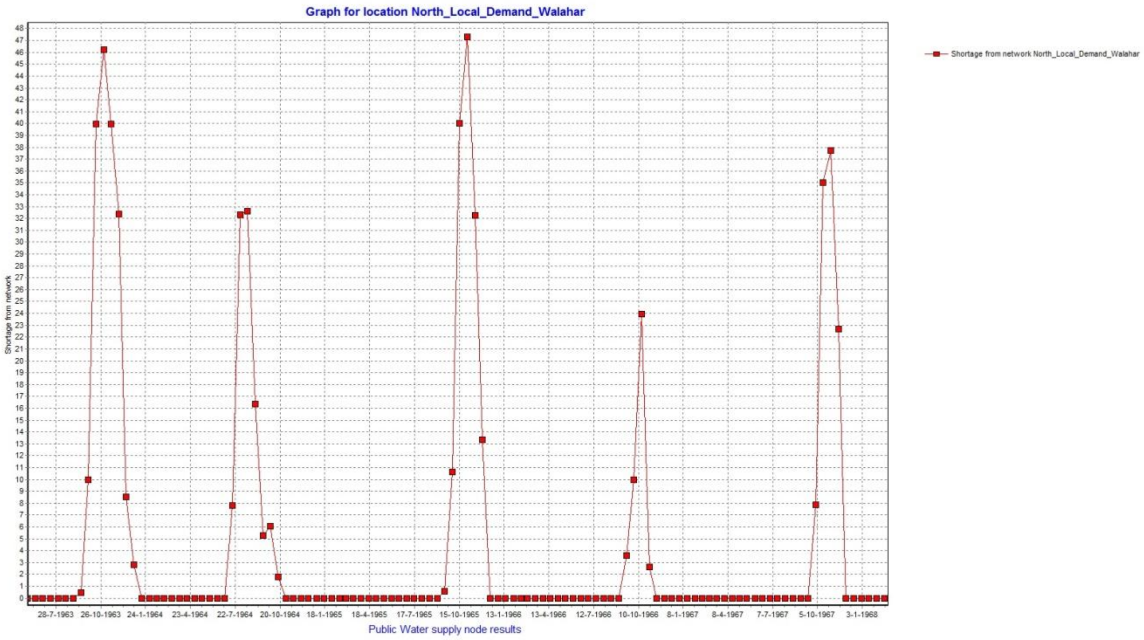
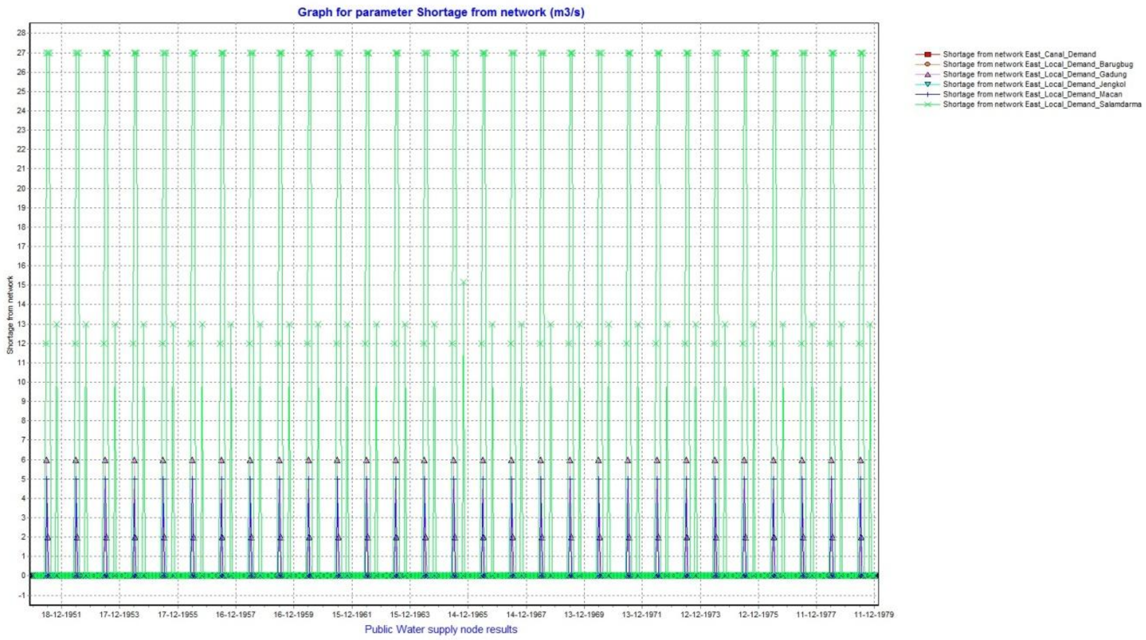
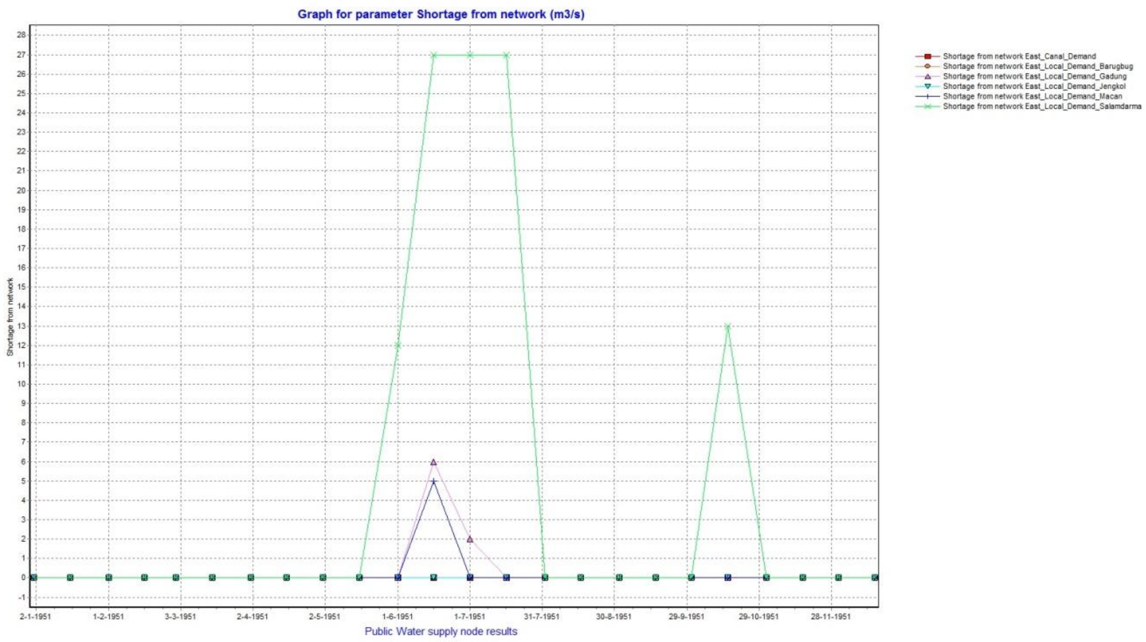
## North System



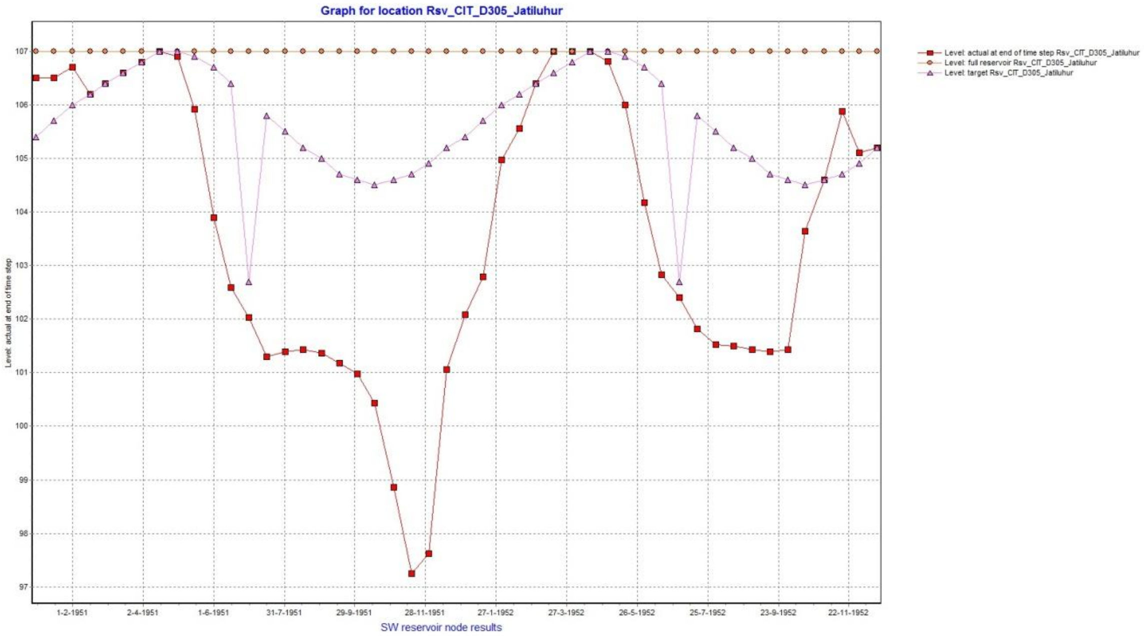



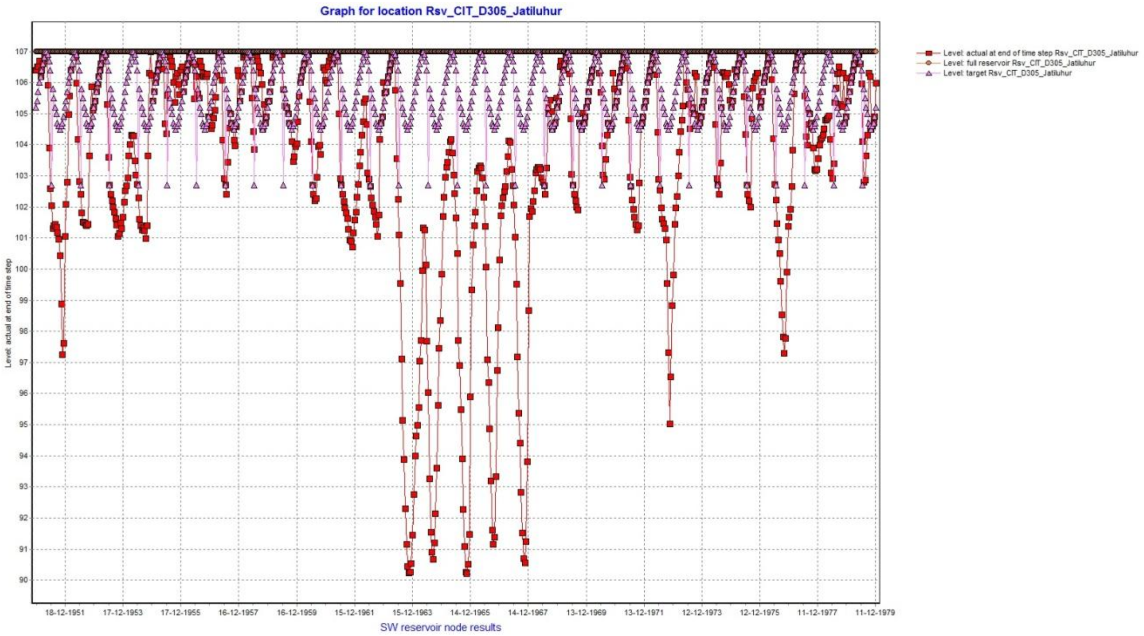
**East System**


Graph for parameter Shortage from network (m3/s)
Shortage from network
Public Water supply node results
Shortage from network East_Canal_Demand
Shortage from network East_Local_Demand_Barugbug
Shortage from network East_Local_Demand_Gadung
Shortage from network East_Local_Demand_Jengkol
Shortage from network East_Local_Demand_Macan
Shortage from network East_Local_Demand_Salamdarma

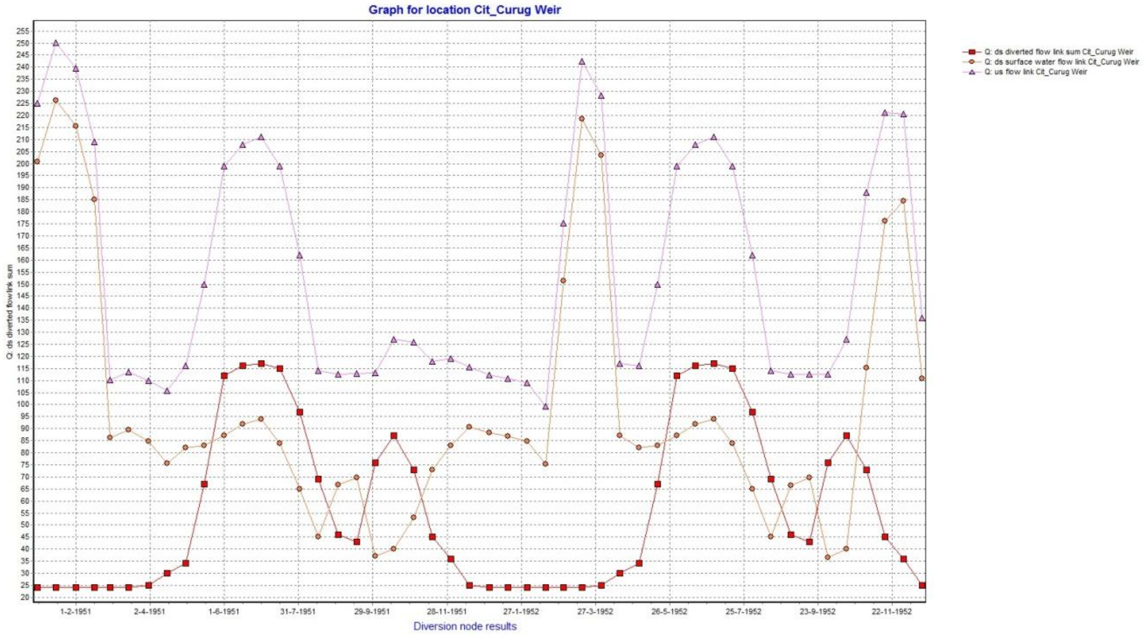

Graph for parameter Shortage from network (m3/s)
Shortage from network
Public Water supply node results
Shortage from network East_Canal_Demand
Shortage from network East_Local_Demand_Barugbug
Shortage from network East_Local_Demand_Gadung
Shortage from network East_Local_Demand_Jengkol
Shortage from network East_Local_Demand_Macan
Shortage from network East_Local_Demand_Salamdarma

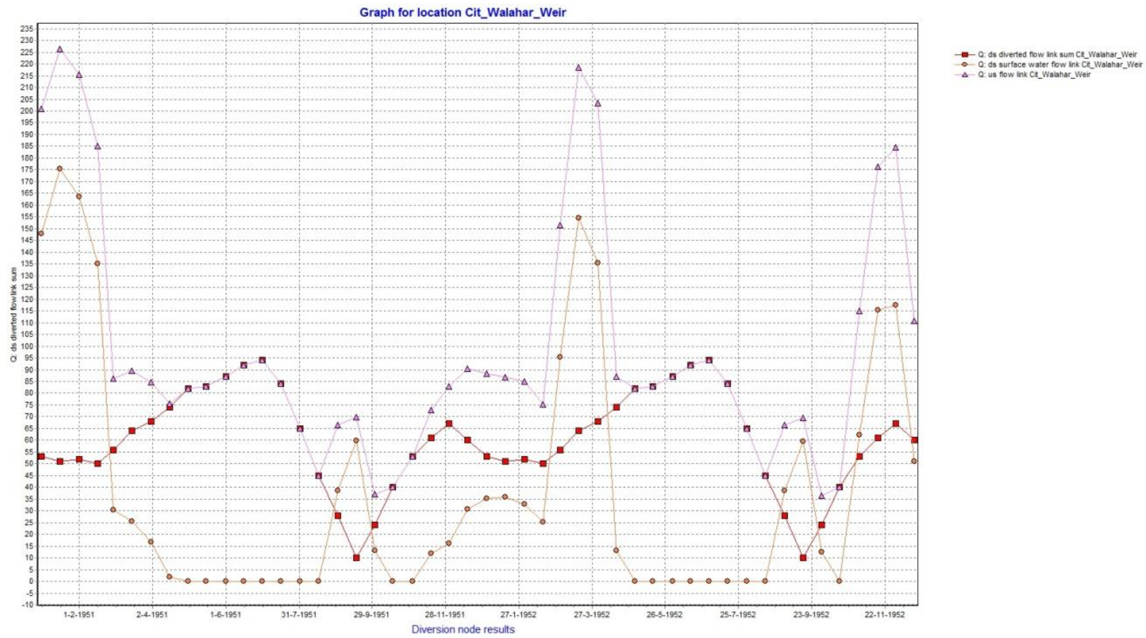
**Jatiluhur**


Graph for location Rsv_CIT_D305_Jatiluhur
Level: actual at end of time step Rsv_CIT_D305_Jatiluhur
Level: full reservoir Rsv_CIT_D305_Jatiluhur
Level: target Rsv_CIT_D305_Jatiluhur
Level: actual at end of time step
1-2-1951
2-4-1951
1-6-1951
31-7-1951
29-9-1951
28-11-1951
27-1-1952
27-3-1952
26-5-1952
25-7-1952
23-9-1952
22-11-1952
SW reservoir node results


Graph for location Rsv_CIT_D305_Jatiluhur
Level: actual at end of time step Rsv_CIT_D305_Jatiluhur
Level: full reservoir Rsv_CIT_D305_Jatiluhur
Level: target Rsv_CIT_D305_Jatiluhur
Level: actual at end of time step
18-12-1951
17-12-1953
17-12-1955
16-12-1957
16-12-1959
15-12-1961
15-12-1963
14-12-1965
14-12-1967
13-12-1969
13-12-1971
12-12-1973
12-12-1975
11-12-1977
11-12-1979
SW reservoir node results

## Walahar Curug Weir



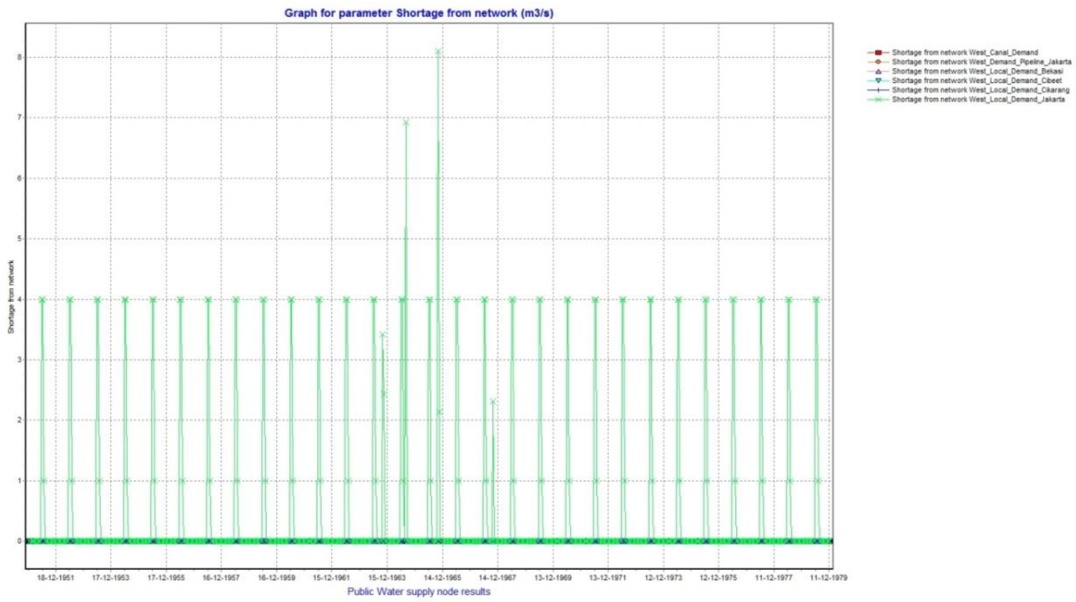
## G.3. "BASE CASE+PIPELINE(S)"

As pointed out in section 3.2.6, the implementing of the pipeline happens in three stages; in each stage the pipeline demand increases with 5 m3/s. The standard demand of 16 m3/s keeps the same. So therefore in this scenario, three "sub-"scenarios are created, in each scenario the total water demand of the pipeline will be increased by 5 m3/s.

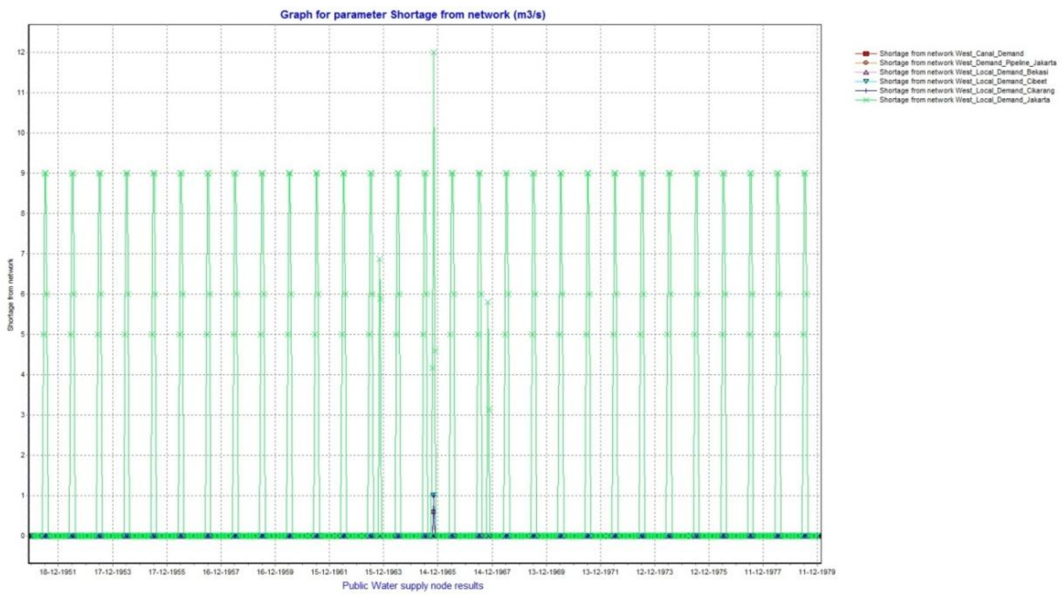
The inflow is kept the same as in Base-Case. The results of the simulation show that directly water shortage occurs in the west system. The most downstream demand node (Jakarta) encounters yearly shortages. With each new pipeline, the shortage increases from 4- to 9 m3/s and from 9 to 14 m3/s.

**West System:**

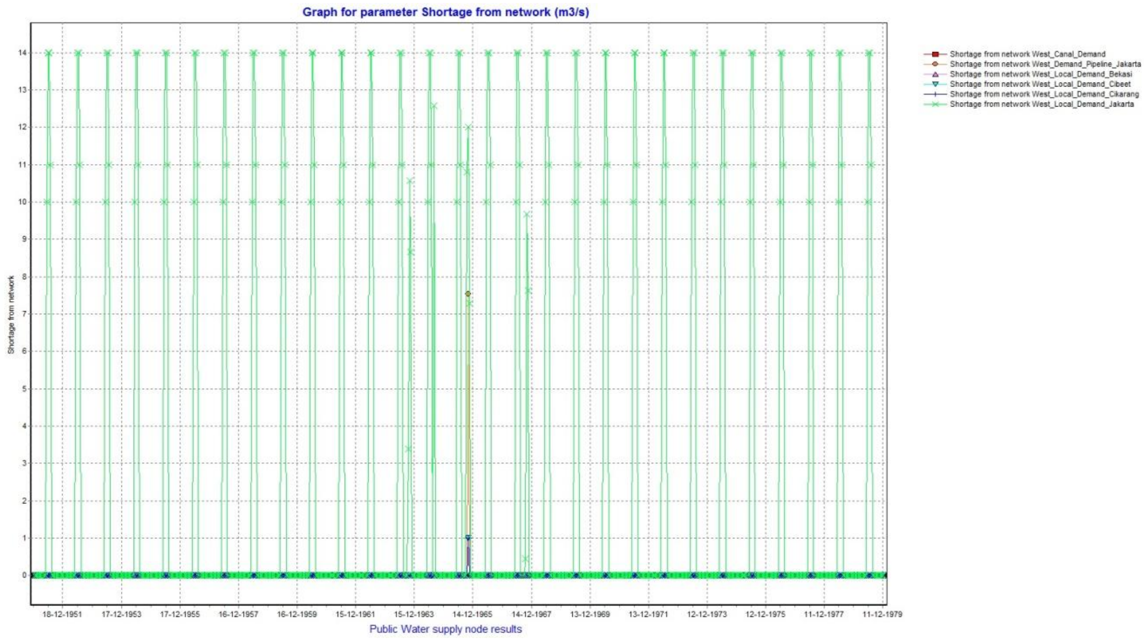
1st pipeline




2nd pipeline

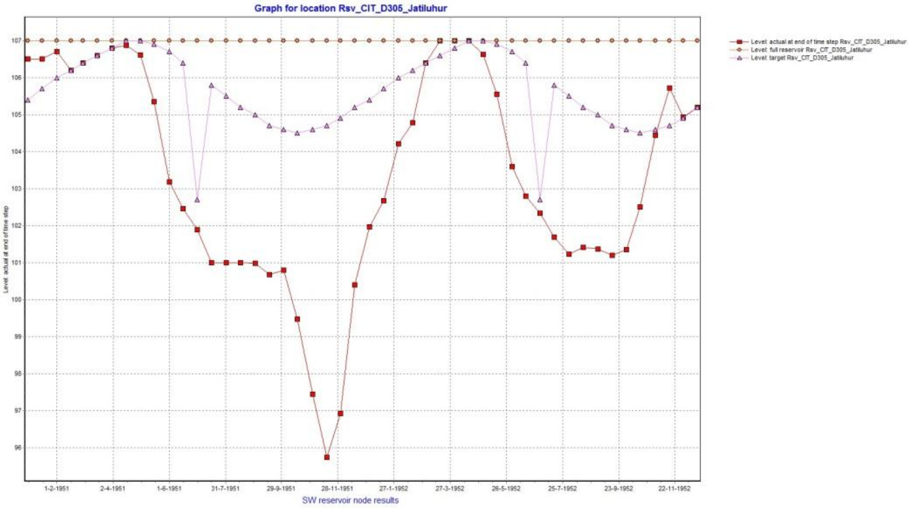


3th pipeline

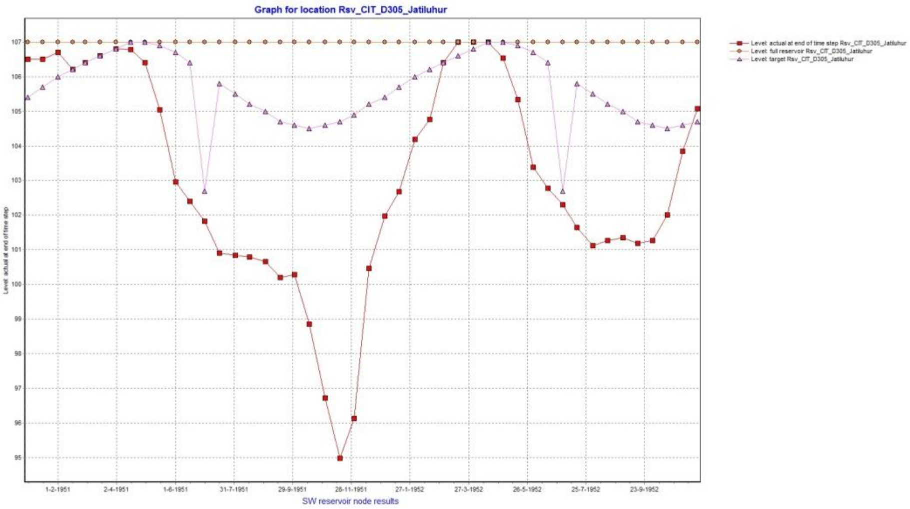


## Jatiluhur Reservoir

1st pipeline




2nd Pipeline




3th Pipeline