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COST MINIMIZATION OF RAW WATER SOURCE BY INTEGRATED WATER SUPPLY SYSTEMS (A CASE STUDY FOR BANDUNG, INDONESIA)

*E. Afiatun[1], S. Notodarmojo[2], A.J. Effendi[2], and K.A. Sidarto[2]

[1]Engineering Faculty, Universitas Pasundan, Indonesia, [2,3]Bandung Institute of Technology, Indonesia

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ABSTRACT: Due to the population growth, the scarcity of raw water presents a challenging problem for the establishment of an effective urban water supply system. In this research, we address the scarcity of water source for a highly populated city, like Bandung, and then minimize the cost associated with the development of effective urban water supply systems. We apply the concept of Integrated Water Supply System (IWSS), a concept that utilizes the treated wastewater as an alternative source of water. This concept will be implemented for the city of Bandung, Indonesia as a case of study. The cost minimization of the raw water supply system is carried out by using the superstructure approach. This optimization of the IWSS includes raw water sources and recycled wastewater. For the proposed scenario, we build a mathematical model that will be used for the optimization of IWSS. This optimization problem is solved using the CONNOPT3 method of GAMS software. The results of this study show that the proposed new IWSS results in less cost, but higher transmitted water, than the existing system (non-IWSS) because, in the new system, the water supply is allowed to flow into the existing Water Treatment Plan (WTP). Factors affecting the cost are length and diameter of the raw water transmission pipeline, the elevation of water resources and water treatment plants, the use of a coagulant, and the use of electricity in the transmission system and the water treatment plant.

Keywords: Integrated water supply systems, Superstructure model, optimization, Cost minimization

1. INTRODUCTION

The main problems in the Water Supply System (WSS) are a scarcity of raw water and increasing of groundwater consumption as a source of raw water for domestic use and industry. Groundwater is a non-renewable source of water that needs to be protected. The high consumption of groundwater has resulted in a decrease in water level and gradually caused a land subsidence due to its continuing impact.

On the other hand, there is a potential of treated wastewater and rainwater as an untapped alternative of raw water. Integrated Water Supply System (IWSS) combines all components of water infrastructure related to water supply, drainage, and wastewater system into a system for efficiency and effectiveness of water management [1]. This research will deal with the cost minimization of the IWSS of raw water sources from several potential sources in the area of Bandung Basin. The cost minimization of the IWSS is carried out by including the variable investment cost of raw water, raw water transmission charges, and the cost of raw water treatment. The aim of this study is to find the optimal use of raw water sources in the city using the IWSS concept by minimizing the cost of reuse of wastewater in a series of IWSS. This will support sustainable water management [2].

The IWSS differs from the conventional WSS due to the reuse of processed wastewater as alternative raw water, whereas in the conventional WSS the processed wastewater is directly discharged into water bodies (Fig.1).

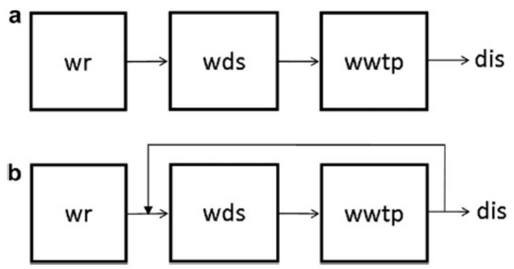

Fig. 1. a. Conventional WSS; b. IUWSS2.
wr = water resources, wds = water demand system, wwtp = waste water treatment plant, dis = discharge

The conventional WSS consists of water resources, water treatment system in accordance with the allocation, and the wastewater treatment plant, where the treated water from the wastewater treatment system is subsequently dumped into the water bodies. Integrated Water Supply System

(IWSS), on the other hand, combines all components of water infrastructure related to water supply, drainage, and wastewater system into a system for efficiency and effectiveness of water management [1].The water resource allocation has focused mainly on attaining quantitative goals in the water supply. In an ideal situation, water resources with high water quality would have been allocated for drinking water improving human health and hygiene, and the water resources with relatively low quality can be allocated to industrial and agricultural uses [2]. Reuse of wastewater in a series of urban water systems into an integrated system will support sustainable water management system [2].

There are several studies on the urban WSS optimization employing various methods. For example, the optimization of the urban water system reliability was done with the method of valuation and contingency [3]. Reliability is an important element of an urban water system. Reliability, in this case, is the reliability of the availability of water supply. With a small cost, customers expect to get a high reliability. The urban WSS now starts considering the level of risk for each of the different types of water use, for example, high-reliability WSS for essential usages related to public health, and the lower level to the fulfillment of watering the garden.

Decentralized WSS is more economical than a centralized system [2], [4]. An optimization study was also conducted on water quality criteria to guide the planning and management of decentralized WSS [5]. This study introduced a method to assess the potential in planning the composition of optimum quality drinking water using membrane desalination and re-mineralization. Using this method, the modeling of mixing various water sources with different quality has been applied.

One of the most commonly used models for the mathematical optimization method is the usage of superstructure model leading to a water source conservation network. This approach includes direct reuse/ recycle and material regeneration [6]. The mathematical model can also be extended to involve limiting factors, such as forbidden connections, the reduction of pipe connections, and cost considerations.

Superstructure models align with the concept of Integrated Water Supply System (IWSS). This model combines all the components of the urban water infrastructure, which includes the components of water resources, water demand systems, and wastewater treatment plant [2]. The advantage of the superstructure approach is its flexibility in combining various process constraints. These constraints can be due to the accumulation of contaminants (for local recycling) or geographic factors (distance between the source and the service area is too far away).

Water resources include the rivers, other surface water, and groundwater, whereas water demand systems are for all purposes including the water services. Urban rivers in Indonesia currently suffer from the untreated wastewater discharged from various kinds of activities [7], [8]. Therefore, wastewater treatment system serves urban domestic waste and industrial waste. Superstructure model aims to take advantage of all the opportunities of water resources and also applies the concept of recycling wastewater.

The superstructure model developed based on the earlier research, but this research focused on minimizing the cost of supplying raw water for drinking water system. The developed model includes:

- The objective function, to minimize the cost of raw water supply
- The use of Mass Balance principles to show the interconnection scheme for the superstructure models
- The constraints to represent the real conditions. For example, the constraints in keeping the interconnection of the Wastewater Treatment Plant (WWTP) to Water Demand System (WDS) used for drinking water, and in minimizing the use of groundwater as a non-renewable source.

2. MATERIALS AND METHODS

The optimization model is the superstructure models involving 2 scenarios.

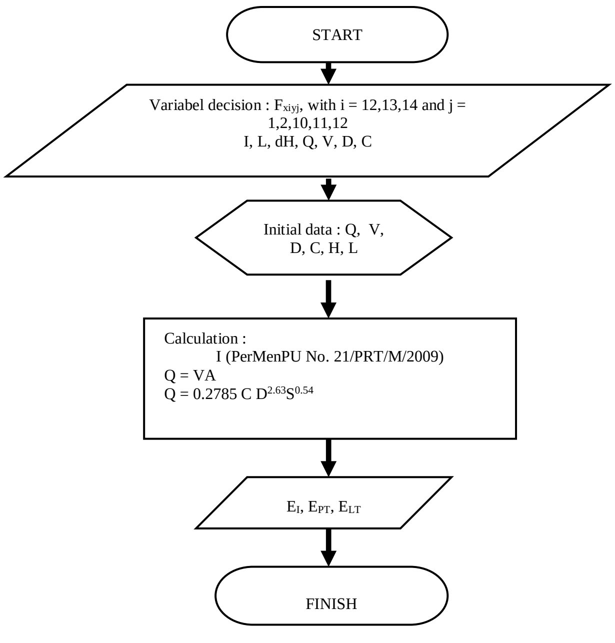

Fig. 2. Subprogram algorithm for the scenario 1

The development of the models begins with the preparation of a WSS scheme based on the mapping results of the existing conditions. The mapping of the existing conditions would be the basis for developing scenarios of the development of WSS and IWSS. Then, the compiled equations of superstructure models are obtained according to the scenarios created by the equations that have been developed in the literature.

The development of equations is done by changing the objective function into minimizing the cost of attempt of raw water. Development of other equations by adding variables that determine the amount of water allocation and attempt costs of raw water. These variables are the investment cost of raw water, water travel investment costs (transmission system), and the cost of raw water treatment [9]-[11].

In this study, the superstructure models for Bandung WSS made up of 2 (two) scenarios. The first scenario was drawn up by the existing conditions still apply appropriate is the case today, with the addition of three (3) new water sources that flowed into the 5 water treatment plant locations both existing and new. The second scenario by changing the existing conditions and added three (3) new water sources so that any water sources either existing or newly allowed to flow to the possible raw water treatment plant. Both of these scenarios apply the concept of IWSS, where re-use treated water becomes one of the new alternative raw water.

The algorithm for scenario 1 (Fig. 2 and 3) shows that each cost variables input into the optimization equation. Cost variables such are investment costs, transmission costs of raw water and raw water treatment costs. The algorithm for the scenario 2 (Fig. 4) shows that there are two ways of completion, the first way to perform input variables related to raw water transmission into the optimization equation. Variable investment costs and raw water treatment costs are calculated separately with the optimization equation and incorporated in the final completion calculations. Completion of the optimization equation is done by software Gams 24.2.2 r44857 released March 4, 2014, with solver Connect 3 [12], [13].

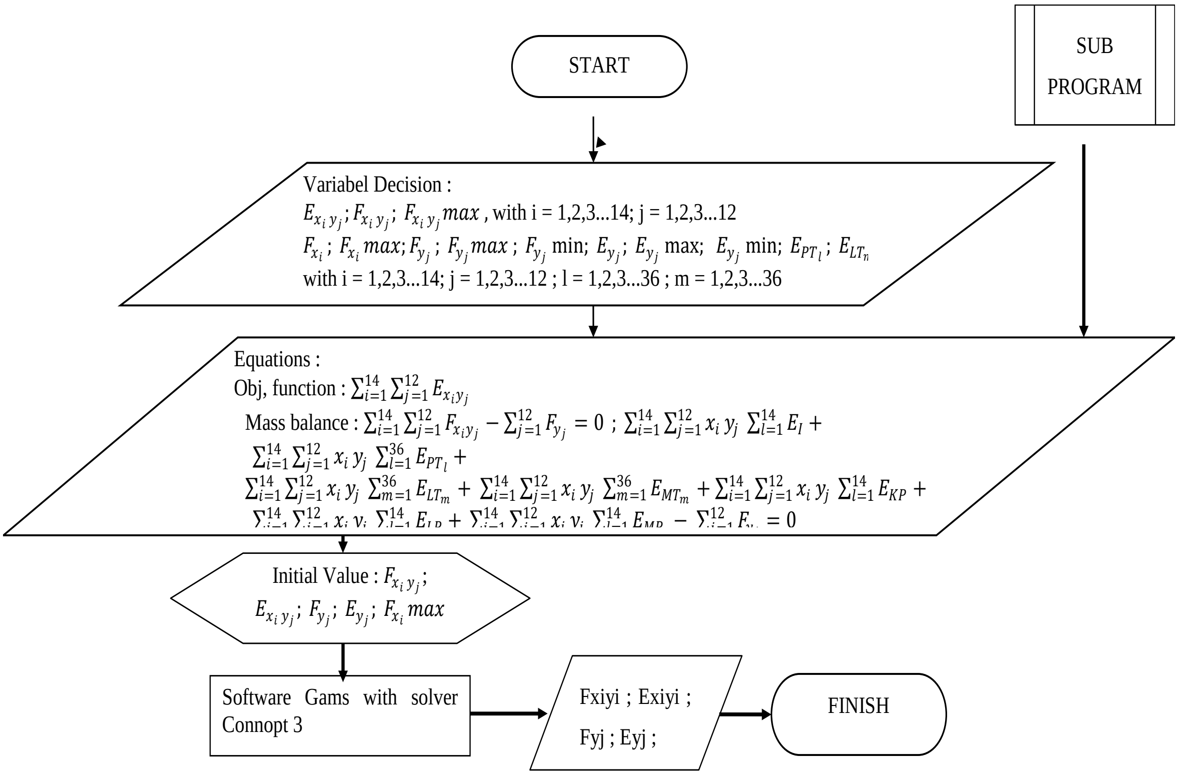

Fig. 3. Algorithm for the scenario 1

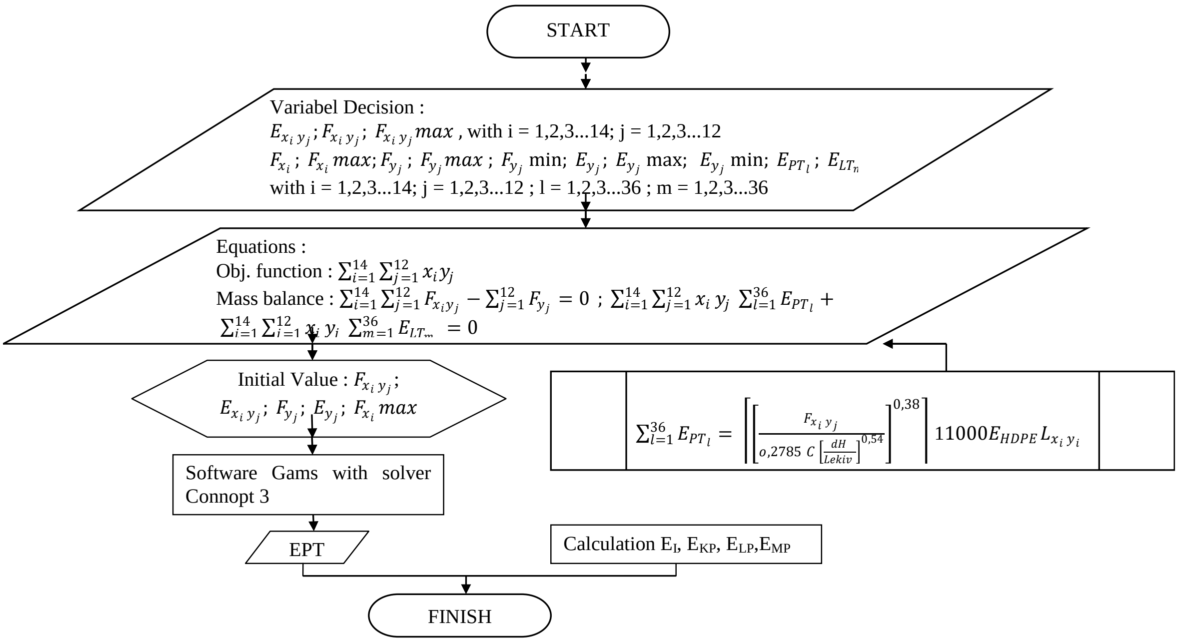

Fig. 4. Algorithm for the scenario 2

2.1 Case Study

The selection of Bandung city as a case study is justified because Bandung is one of the highly populated cities, and the raw water data and the performance of WSS are available for Bandung city. Furthermore, Bandung city as a city in Indonesia represents the characteristics of cities in tropical and developing countries that have specific parameters in WSS. The location of the study area can be seen in Figure 5.

Perusahaan Daerah Air Minum (PDAM) is a regional water company which is responsible for managing the water supply system of a city or districts in Indonesia. Water needs in Bandung city are calculated based on the projected population increases up to 20 years with the water needs per person per day is 150 L/p/day [15]. A current population of 3.1 million people with a growth rate of 2.1 with the main water needs for domestic needs [16]. Projected population growth is calculated using the arithmetic method, resulting in that the population of Bandung city in the year 2025 is 3.7 million with the water needs of 6800 L/sec [16]. Clean water needs from year to year increase due to population growth, technological progress and improving the local economy. Discharge treated raw water until 2015, only amounted to 2937 L/sec which is relatively fixed, while the raw water coming from groundwater and water springs are declining [16].

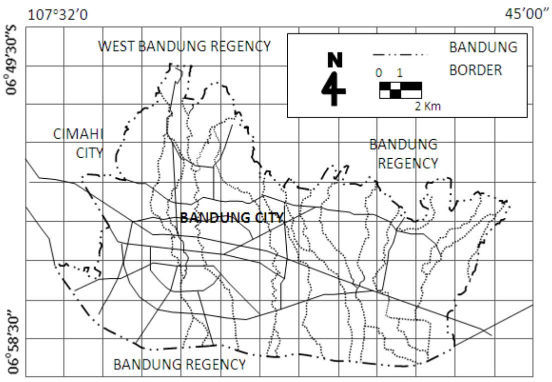

Fig. 5. Administrative Boundary Map of Bandung City, Indonesia [14].

3. RESULTS

3.1 Scheme of Superstructure Model

The scheme of superstructure models is created to derive the mass balance equations and other equations involving the determined limiting factors. In this study, the superstructure models for Bandung WSS will be made up of 2 (two) schemes. The existing condition as seen in Figure 6, the existing water resources consist of rivers, water springs, and groundwater that flow into the existing Water Treatment Plant (WTP) to serve system for water demand, both domestic and non-domestic. The effluents from the domestic portions are discharged into septic tanks, partly discharged to municipal sewerage to be processed in WWTP Bojongsoang. The treated water in the existing condition of WWTP Bojongsoang is directly discharged into water bodies.

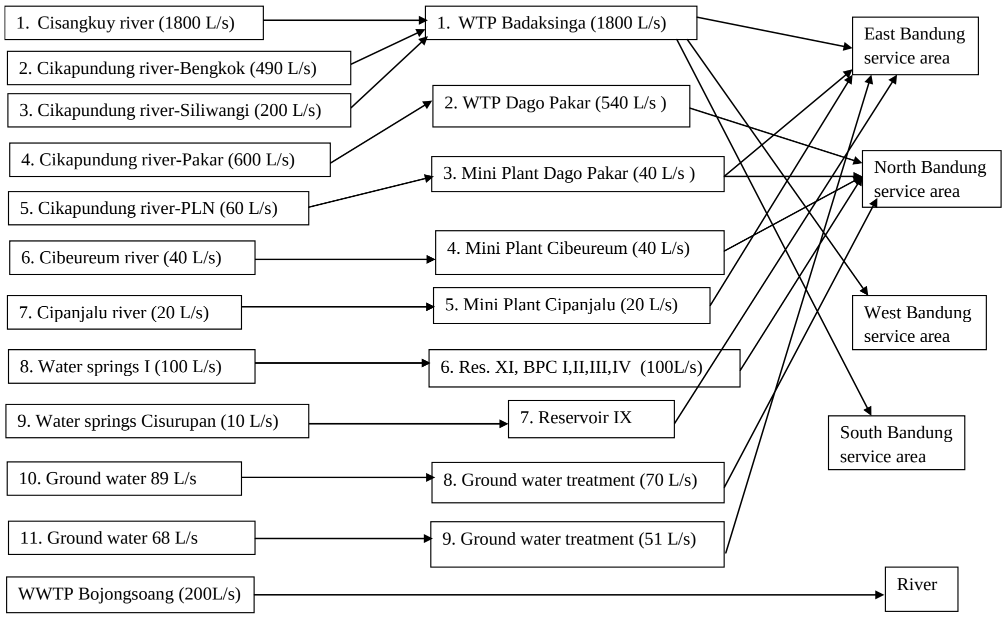

Fig. 6. Existing condition of Bandung City WSS

The scenario 1 of Bandung city IWSS was created by adding the three new water sources namely Saguling reservoir, Cisangkuy river, and reuse of WWTP Bojongsoang that integrated into one service system with the existing condition. This scenario also considers that the treated wastewater coming from WWTP Bojongsoang is directly distributed to the new WTP where the first one is to conduct advanced treatment. The scenario can be seen in Figure 7.

The scenario 2 of Bandung city IWSS created by changing the existing conditions and added three (3) new water sources so that any water sources either existing or newly allowed to flow to the possible raw water treatment plant. The scenario can be seen in Figure 8.

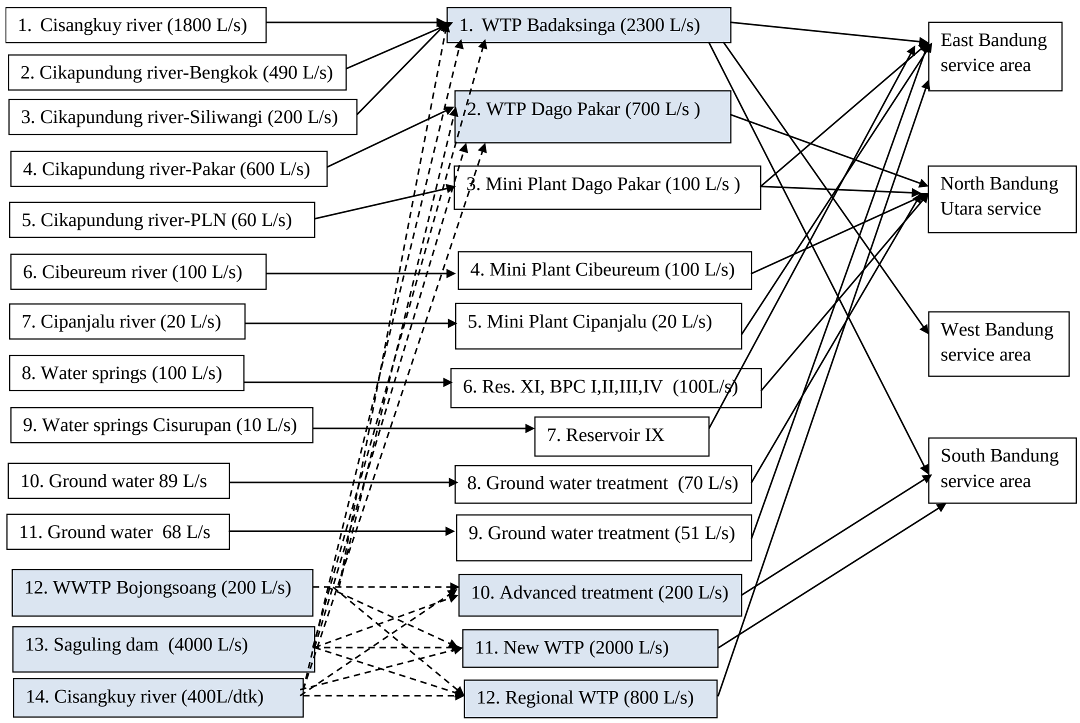

Fig. 7. Scenario 1 of Bandung City IWSS

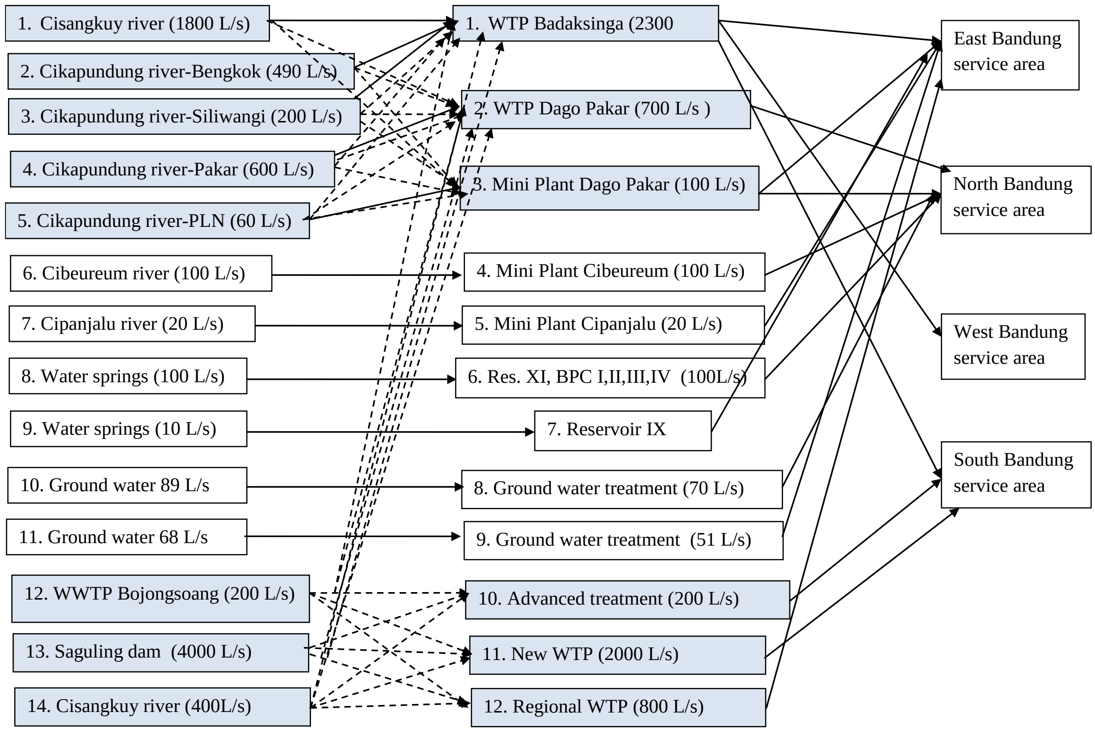

Fig. 8. Scenario 2 of Bandung City IWSS

3.2 Case Study

The model equations are derived from the superstructure scheme by Lim, et al., 2010 as shown in Equations (1) to (9) [2]. The difference with ours is the objective function where we minimize the cost of raw water supply. The costs are calculated in this scenario is the investment cost of raw water, raw water transmission costs, and the cost of raw water treatment.

Formulation of an optimization model for superstructure models such as the following:

- The objective function is to minimize the cost of raw water supply
- Material balance for the inlet sections of WTP systems; the model consists of the material balances for the debit from all water resources from within and outside the city including the treated water from the WWTP as an alternative of raw water.
- Material balance for the outlet section of the wastewater treatment plant; the mass balance explains that all the water coming out from the WWTP is the amount of water from the WWTP, which is distributed throughout the service system plus water discharged into water bodies.
- The maximum discharge constraints represents the allocated water based on the relevant permit
- The constraints of discharge define the minimum discharge of the water system needs
- The maximum discharge from the WWTP indicates the limit of discharge that can be used from all WWTP to supply all the demands and to discharge.
- The constraint for preventing the use of non-renewable groundwater.
- The constraint for raw water treatment cost.

3.3 The Completion of the Superstructure Model Scheme

The optimization for scenarios 1 and 2 follow the scheme in Figure 4 and 5.Scenario 1 is that the entire system is still run according to the existing conditions but by adding three new water sources. The three of new water sources flowed into two (2) existing WTP that still possible to process raw water, and the three (3) location of new WTP, i.e. advanced WTP, which will recycle water from WWTP Bojongsoang, new WTP to treat water from Saguling, and Regional WTP. In Figure 4 and 5 can be seen that a clear line is a raw water flow towards each WTP on existing conditions, while the dashed line is a plan for new raw water flow to the WTP that allows receiving additional raw water, both existing or scenario of WTP. Transmission piping diameter calculation refers to the Hazen Williams equation. Other costs will be calculated based on the equation of optimization, such as investment costs, and maintenance costs of the transmission system refer to the Regulation of the Minister of Public Works No. 21 the Year

2009 on Technical Guidelines Development Investment Feasibility WSS.

The results of the cost minimization for the simulation scenario 1 can be seen in Figure 9.

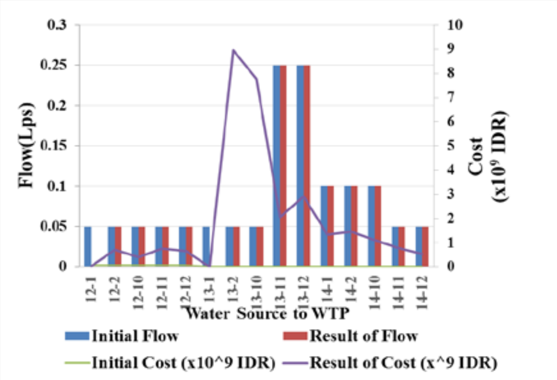

Figure 9. The result of the calculation of cost minimization for Scenario 1

The second scenario was carried out by changing the whole existing system and adding new water source that is expected to meet all the water needs in Bandung city in 2030. Cost factors are divided into 2 (two) groups, namely the costs related only to the quantity of raw water and the costs that affect the raw water flow toward each WTP. Cost factors that related to the quantity of each raw water are the investment cost of raw water, in this case, the cost of making the intake and raw water pumping costs, and the cost of each raw water treatment. While the cost of raw water affecting flow toward each WTP is a cost in raw water transmission system, namely the cost of piping, raw water pumping costs, and maintenance costs of the transmission system.

The results of the cost minimization for the simulation scenario 2 can be seen in Fgure10.

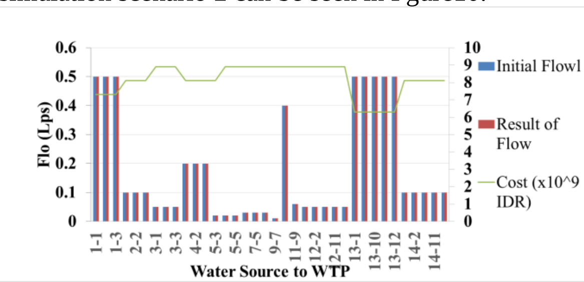

Figure 10. Raw water distribution and total cost required in Scenario 2

4. DISCUSSION

Based on the cost minimization results in Figure 9, it can be seen that the movement of raw water into account cost variables was included in the equation, especially cost variable of transmission piping system that considers the distance and head loss. The amount of water that can be streamed from a new water supply of 2.1 m^3/s, so that when added to the amount of raw water in the existing condition of 3,537 m^3/s, the water needs in the city of Bandung will be fulfilled until 2030 [14].

In Figure 9 can be seen that there is no flow of water processed from the WWTP Bojongsoang and Saguling to WTP Badaksinga. This is expected because of the distance of both the water source is very far from the WTP Badaksinga.

Based on the objective function of optimization equation, i.e. minimizing the cost of the attempt of raw water can be compared to both scenarios that have been tested as in Figure 11. Comparison of scenarios 1 and 2 was made only on the raw water supply system owned by the two scenarios, so some existing scenario omitted.

From Figure 11, it can be seen that in the scenario 1, the system changes only occur at new water sources, water sources no.12, 13, and 14 that are drawn to the WTP number 1, 2, 10, 11, and 12. Scenario 2 allows the existing raw water flow no. 1, 2, 3, 4, and 5 to the existing WTP number 1, 2, and 3 and passes a new water supply to the existing WTP number 1, 2, and 3 as well as to the new WTP number 10, 11, and 12.

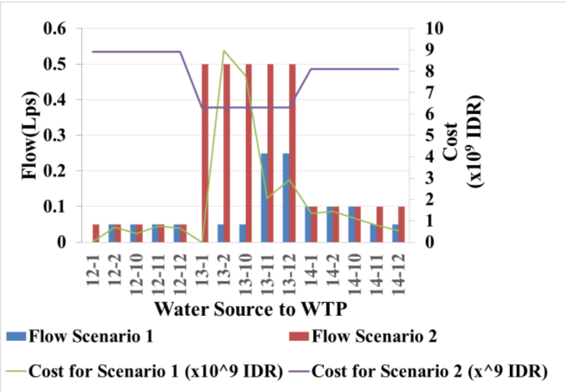

Figure 11. Comparison of results Scenario 1 and Scenario 2

The results were compared only look to the attempt of new water sources. Scenario 1 is based on a new raw water can flow of 2.1 m^3/s. while based on Scenario 2 new raw water can be channeled into existing and new WTP as much as 3.25 m^3/s. Cost required for Scenario 1 is IDR 29.48×10^9 while the cost required for Scenario 2 is IDR 11.65×10^9. Based on consideration of the amount of raw water flowed and the amount of attempt cost of raw water required, then Scenario 2 can be said more optimal because it can flow more raw water with a cheaper attempt costs.

5. CONCLUSION

The conclusions that can be obtained in this study are:

- The concept of integration is applied to the WSS in this research is to utilize the processed domestic wastewater as an alternative raw water source.
- The objective function of the optimization equation is compiled minimizing of attempt cost of raw water.
- Scenario by utilizing the existing system, completely supply the water less than the scenario that is renewing most of the existing system. This happens because of a new raw water also allows also flow into the existing WTP.
- The cost of the attempt of raw water by utilizing the existing system is fully greater when compared to the cost at the time partly refurbished existing system.

6. ACKNOWLEDGMENTS

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