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System Dynamics Modeling for Sustainable Water

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Abstract: 1945 Constitution Article 33 paragraph (3) states that the utilization of water resources must be aimed to the greatest extent possible for the prosperity of the people. The balance between the need for clean water and the availability of clean water needs to be managed in such a way that its utilization meets the criteria for environmental and sustainable integration. The purpose of writing this paper is to provide an overview, how to make a model about the relationship between the availability of clean water and the need for clean water at this time and anticipation going forward, so that the scarcity of clean water can be controlled and anticipated beforehand. The method used is system dynamics with the development of fixed that fail. The result obtained is that a system dynamics model can be used to show the behavior of the clean water ratio model with an alternative optimal solution for changing the positive loop into a negative loop, and can be simulated to obtain a picture or condition of clean water availability in the future.

***Keywords:** system dynamics, modeling, fixed that fail, clean water, availability ratio*

I. INTRODUCTION

Water resources as part of natural resources in the Guidelines for State Policy (GBHN) 1999-2004 are mentioned as directed as possible for the prosperity of the people by taking into account the preservation of environmental functions and balance, sustainable development, economic interests, and culture of local communities the operation is regulated by law. Water resource management and water management must be based on the principle of participation by involving the community in decision making in all aspects of activities (planning, implementation, supervision, control, and financing) to encourage the growth of commitments of all interested parties [1].

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Issues relating to various types of water use that tend to increase, both in quantity and quality so that it is very possible that there is an imbalance between water needs and water availability, an increase in the quantity of clean water due to an increase in population and human activities / activities and quality occurs due to increasing demands from increasingly established communities [2].

The problem of using clean water shows dynamic signs, which means that the problem is related to a quantity that changes with time that can be poured into graphs with its variables in the form of time series and the problems encountered can be described in the form of reciprocal relationships. By describing the real situation regarding the use of clean water into a model and showing the relationship between water availability and water needs, then the model can be developed as a based for experimental investigations that are relatively inexpensive and time-saving when compared to conducting experiments on a real system [3].

For the condition of clean water in the Special Capital Region of Jakarta (DKI), the need for clean water is also increasing, the population is increasingly difficult to get clean and healthy water, in addition to being polluted ground water is also a problem of limited clean water in the City. Comparison between the need for clean water and the availability of clean water needs to be controlled as an indicator of the sustainability of a city in terms of the use of clean water [5], because the degradation of the quantity of clean water can affect macroeconomic factors that are always related and in line with the demographic factors of urban areas [6].

Management of the quantity and quality of water is very dependent on the level of management of water resources in each region, the diversity of water uses that vary (for agriculture, industry, and social), demographic conditions and people's perceptions about water.

Considering the above conditions, DKI Jakarta as the National Capital and barometer for other regions, is expected to be able to set an example in the management of water resources that are strategic for economic development, social development, and integrated, thoughtful and professional environmental development.

Water use ratio which is a comparison between water demand and water availability, can be seen as a picture of water use in an area. The high ratio of water will be a problem because of limited water resources which means it will also affect water availability. The high water ratio can affect people's perceptions of clean water scarcity and will encourage increased efforts to comply with existing laws and encourage the government to also complete more strategic water regulations in the effort to fulfill clean water to the maximum tolerance limits in accordance with the environmental conditions of water resources, this effort will increase the availability of clean water which means it can also reduce the ratio of the use of clean water which is a solution of the existing problems.

At a certain time this solution is acceptable, but on the other hand, increasing water availability which means an abundance of clean water in the city will have an impact on people's bad behavior in utilizing water and perceptions of prosperity that will affect population growth and this is actually a result that is not is desired.

This condition if treated as business as usual will cause unsustainability so intervention is needed.To calculate the amount of water needs that will be used by residents every day, it will use some secondary data from several studies that have been done. The average water requirement per person in one day is 175 liters [13]. Related to the concept of water recycling as an intervention or policy taken is the concept of recycling which was developed by the N.S.W Department of Health. The concept integrates waste water channels into reservoirs for filtering and then redistributes to recycled waterways. The visualization of the concept of water recycling is as follows.

Related to the concept of water recycling that will be reused by the community, it is necessary to pay attention to the specifications of the use of water that can use recycled water, in addition to the psychological community who are afraid of using recycled water to meet water needs are also considered. According [12], there are some human activities that can use recycled water, namely to flush the toilet after defecating, watering plants and washing cars. The amount of water that can be recycled is as much as 100 liters per person every day, meaning that every person who uses recycled water only needs 75 liters of water per day or saves 57.24%.

II. LITERATURE REVIEW

The implementation of system dynamic method is closely related to the problem of dynamic tendencies of complex systems, related to the pattern of system behavior over time. system dynamics have a tendency of activities that occur continuously in every system that runs based on the structure of cause and effect that is formed from the running system processes. Understanding system dynamics can be interpreted about how a system as a network of interrelated elements can affect a number of other components, the process of system dynamics produces the principle of feedback by exchanging information between components. Through the System dynamics method, phenomena that occur in the real world can be abstracted into more explicit models that are able to explain and describe models that function as system prototypes.

The steps to build a system dynamics model are carried out through the following 4 steps [4]:

1. Compilation of concepts in a CLD (Causal Loop Diagram) model.
   The first stage is conceptualization, the symptoms or processes to be imitated need to be understood in advance by determining the elements that play a role in these symptoms or processes in the Causal Loop Diagram.
2. Making flow chart models or SFD (Stock and Flow Diagrams).
   Based on the concept of ideas obtained in the previous stage, the idea is formulated as a model in the form of description, picture, or formula, where the model is a form that is made to imitate a phenomenon or process. The model in the form of pictures is called Stock and Flow Diagrams.
3. Simulation in the form of diagrams and time series tables.
   If the stock flow diagram is formed, the simulation can be run using the model. Simulations can be repeated repeatedly until an effective model behavior is obtained.
4. Validation of simulation results.
   After the simulation results are obtained, validation is performed to determine the compatibility between the results obtained with the symptoms or imitated processes. The model can be stated either if the error or deviation of the simulation results of the symptoms or process is imitated small (under 10%).

Stages of the construction of the model is done as follows:

1. Developing the concept in a model of CLD.
2. Develop SFD model or flow charts.
3. Input data.
4. Simulation of a timing diagram and table time.
5. Model Validation.
6. Policy Analysis (Sensitivity Test).

Furthermore, in chart form, the steps above can be presented as Figure 1.

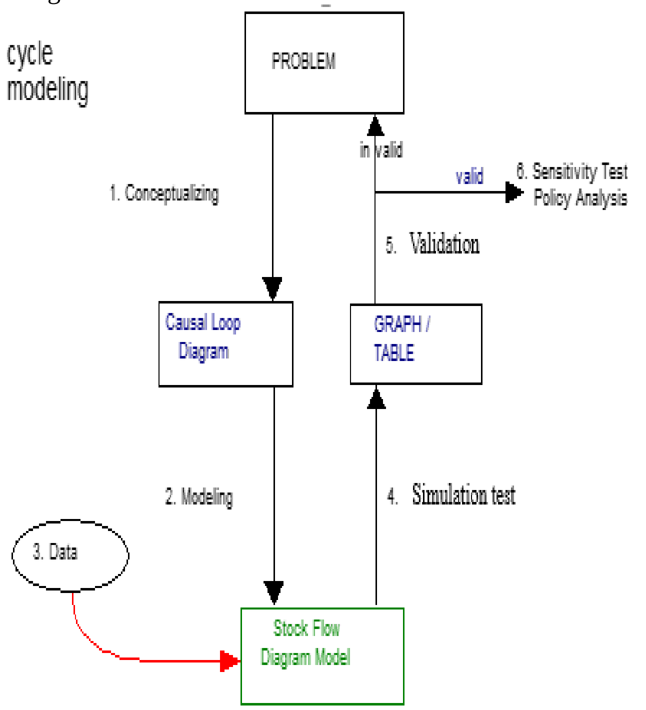

Fig. 1. System Dynamics Cycle Model

III. METHODOLOGY

System dynamics is a method to learn about the world around us. In system dynamics we used different approach to solve the problem. While in other research people usually try to breakdown the problem into small parts, system dynamics solve the problem by seeing the big picture of the problem.

The main concept of system dynamics is understanding how objects in a system interacts with each others. [3]

System dynamics simulate the world by using the causality relationship between variables and mathematical equations. This relationship requires variables to create a closed loops. [4] In other words, the variables used in system dynamics can be divided into 3 types:

1. Level variable which shows the changes continously
2. Rate variable which shows the changes in certain times
3. Auxiliary variable which influence rate variable

To use system dynamics, we need to create a model which consists of Causal Loop Diagram that used to describe the hypothesis about basic mechanism from causality relationship that happen inside the system in certain times [5] and Stock Flow Diagram which describe the causality relationship in the model that will be used in the simulation. Figure 2.

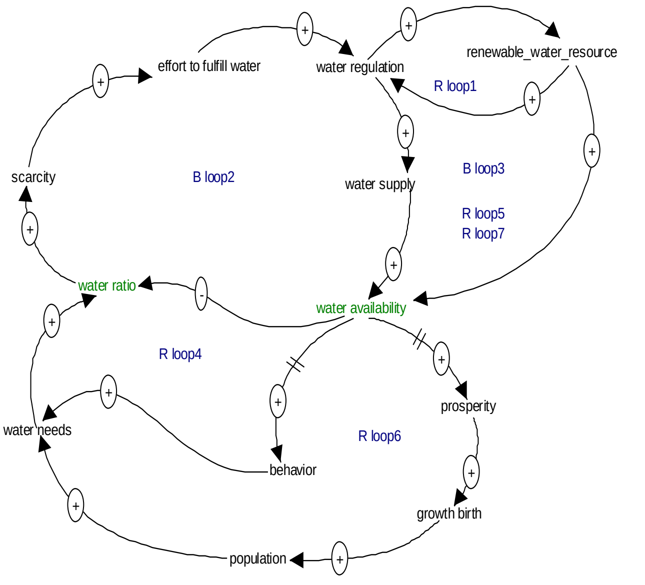

Figure 2. Causal Loop Diagram

To simulate the model, author used several data released by Water Supply Statistics, BPS-Statistics of DKI Jakarta Province 2013 – 2015 and 2015-2017.

Table 1: Population, Birth rate and Death rate

Year	Population	Birth	Death
2013	9.97	1.61%	0.07%
2014	10.08	1.74%	0.08%
2015	10.18	1.51%	0.07%
2016	10.28	1.64%	0.06%
2017	10.37	1.59%	0.07%
2018	18.48	1.66%	0.07%
Average		1.63%	0.07%

Table 2: Water Production Capacity – Litre per second

Year	Potential	Effective	Prosentage
2013	15200	14130	92.96
2014	15200	14544	95.68
2015	15200	14959	98.41
2016	16200	15956	98.49
2017	17500	16869	96.39
Average		15291	96.39

Table 3: Water Production Capacity – Cubic Meter per year

Year	Liter per second	Water in Cubic Meter
2013	14130	445,603,680
2014	14544	458,817,264
2015	14959	471,747,024
2016	15956	503,188,416
2017	16869	531,980,784

By using the Casual Loop Diagram author can develop Stock Flow Diagram that describe more specific model that can be simulated to achieve see changes in the variables used in this research. Figure 3.

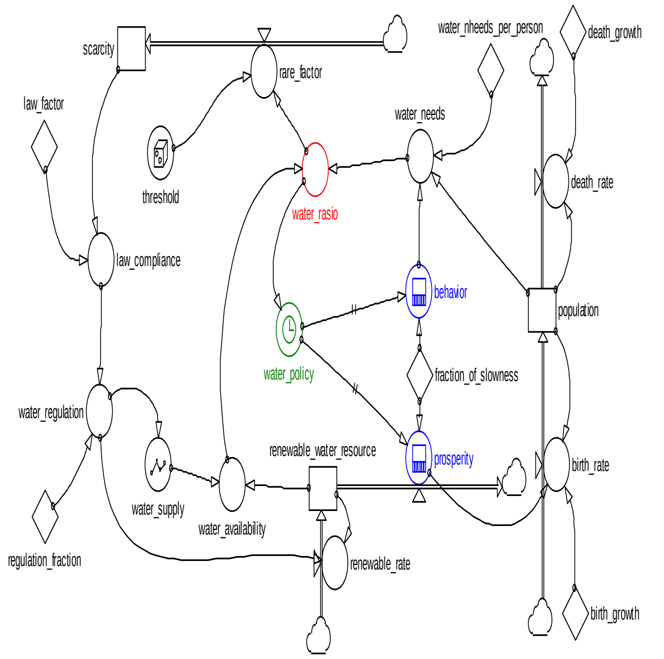

Figure 3. Stock Flow Diagram

To get the results from simulation, author used several mathematical equations to find the changes in each variables. Some of the equation are listed below:

init population = 9966931
flow population = +dt*birth_rate
-dt*death_rate
doc population = DKI Population
unit population = People
init renewable_water_resource = 2000000
flow renewable_water_resource = +dt*renewable_rate
-dt*prosperity
doc renewable_water_resource = Number of additional water per year
unit renewable_water_resource = Meter Cubic
init scarcity = 0
flow scarcity = +dt*rare_factor
doc scarcity = water scarcity
unit scarcity = %
aux birth_rate = ((birth_growth/100)*population*(100+prosperity))/100
doc birth_rate = Birth Growth
unit birth_rate = people per year
aux death_rate = (population*death_growth)/100
doc death_rate = Death Growth
unit death_rate = people per year
aux prosperity = DELAYMTR(water_policy, fraction_of_slowness,1,0)
doc prosperity = delay factor
unit prosperity = %
aux rare_factor = PULSEIF(water_rasio>threshold , 0.1*threshold)
doc rare_factor = Factor of water scarcity level, assume 10% of threshold
unit rare_factor = %
aux renewable_rate = (renewable_water_resource*water_regulation*0.1)/100
doc renewable_rate = additional water
unit renewable_rate = Cubic Meter per year

aux behavior = DELAYMTR(water_policy, fraction_of_slowness,1,0)
doc behavior = Bad community behavior for water utilization

unit behavior = %
aux law_compliance = IF(scarcity<100, scarcity+law_factor, 100)
doc law_compliance = Regulation compliance
unit law_compliance = %
aux threshold = RANDOM(60,70,1)
doc threshold = Balanced water ratio (Threshold)
unit threshold = %
aux water_availability = renewable_water_resource+water_supply
doc water_availability = Number of water supply
unit water_availability = Cubic Meter
aux water_needs = (population*water_nheeds_per_person *(100+behavior))/100
doc water_needs = Number of water needs
unit water_needs = Cubic Meter
aux water_policy = PULSE(water_rasio,2, 5)
doc water_policy = Water Rasio adjustment policy, very 5 year and start at second year.
unit water_policy = %
aux water_rasio = (water_needs/water_availability)*100
doc water_rasio = Comparison between water need and water availability
unit water_rasio = %
aux water_regulation = IF(law_compliance<100, law_compliance+regulation_fraction, 100)
doc water_regulation = Water Regulation
unit water_regulation = %
aux water_supply = ((100+water_regulation)*GRAPH(TIME,2013,4,[445603680,458817264,471747024,503188416,531980784"Min:445603680;Max:531980784"]))/100
doc water_supply = Water production data DKI Jakarta Year 2013-2017, Ref. Jakarta dalam Data 2018
unit water_supply = Cubic Mater
const birth_growth = 1.3
doc birth_growth = % birth growth
unit birth_growth = % per year
const death_growth = 0.3
doc death_growth = % Death Growth
unit death_growth = % per year
const fraction_of_slowness = 5
doc fraction_of_slowness = Expected delay process
unit fraction_of_slowness = year
const law_factor = 5
doc law_factor = Fraktion of regulation compliance
unit law_factor = %
const regulation_fraction = 5
doc regulation_fraction = Fraktion of Water regulation
unit regulation_fraction = %
const water_nheeds_per_person = 60
doc water_nheeds_per_person = Number of water need per people per year.
unit water_nheeds_per_person = Cubic Meter
spec start = 2013.00000
spec stop = 2050.00000
spec dt = 1.00000
spec method = Euler (fixed step)

The simulation results in graphical form can be seen very clearly, Figure 4.

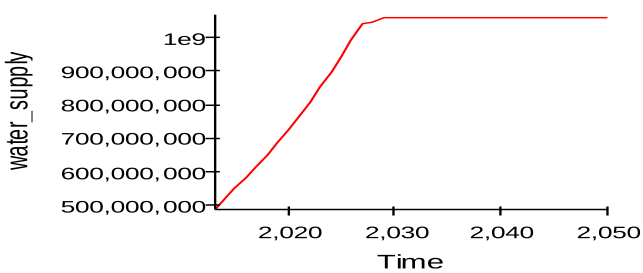

Figure 4: Water Supply Simulation

The initial state of Renewable water resource in the future. Figure 5.

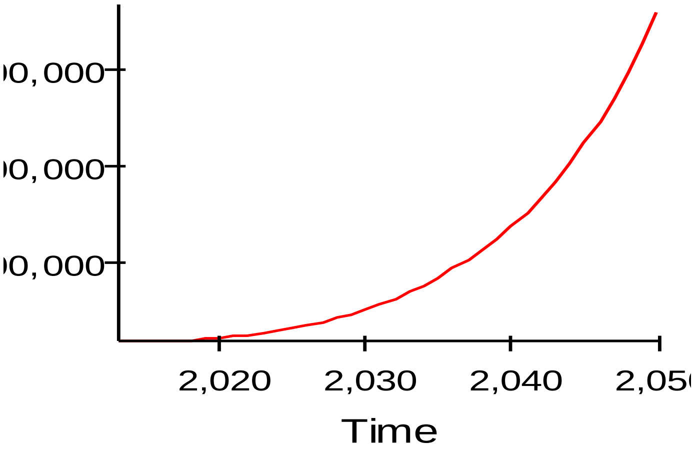

Figure 5. Renewable water resource

The main variables in the structure of the problem are population, surface ground water use, shallow groundwater volume, and water volume gap. The rate of addition of shallow ground water is influenced by existing green open space, the wider the green open space increases the volume of existing shallow ground water. The use of shallow groundwater is greatly influenced by the population and the efficiency of the use of shallow groundwater.

IV. RESULT AND DISCUSSION

Population growth in the DKI Jakarta area based on time series data and the results of the 2003-2040 simulation show exponential growth behavior. This is due to population growth continues to increase.

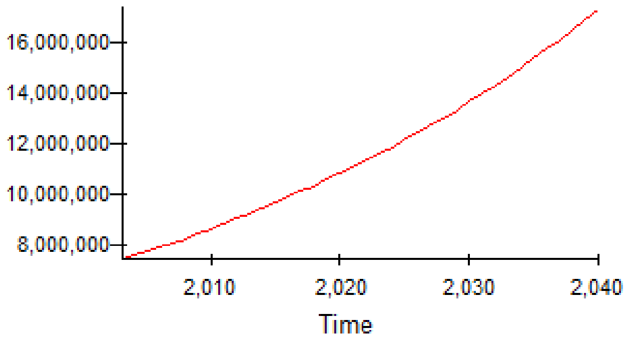

Figure 4. Graph of population growth

In real conditions, along with population growth, the volume of clean water will decrease and water usage will increase, as in Figure 5.

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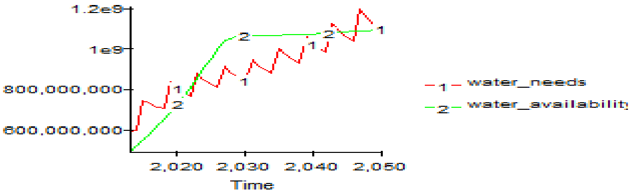

Figure 5. Graph of Water Needs and Water Availability

However, after intervention in water use efficiency after 2010 there will be a shift as the data in Table 4 and the graph shown in Figure 6.

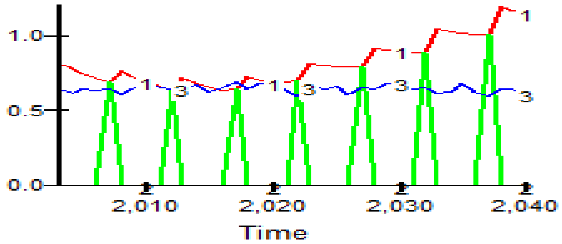

Figure 6. Graph of Water Needs and Water Availability, Water Ratio

Based on the data Tabel 4, it appears that the demand for water continues to increase from year to year in proportion to the increase in population. This becomes the basis for intervention. If an intervention is carried out there will be a decrease in the amount of water use, the results of the intervention can be seen in the 2011 data. While a comparison between the amount of shallow groundwater volume and water use can be seen in Figure 7.

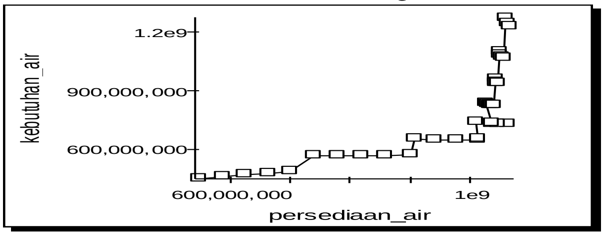

Figure 7. Graph XY: Water Needs and Water Supply

Table 4. Data on the difference between water volume and water usage

Time	kebutuhan_air	persediaan_air	rasio_air
2,003	453,267,660	549,428,908.40	0.825
2,004	462,333,013	586,694,538.40	0.788
2,005	471,579,673	623,290,620.93	0.757
2,006	481,011,267	661,916,554.82	0.727
2,007	490,631,492	700,651,886.93	0.70
2,008	570,531,323	740,533,492.23	0.77
2,009	569,436,775	777,599,631.93	0.732
2,010	570,559,495	817,146,105.97	0.698
2,011	573,553,101	859,029,816.19	0.668
2,012	578,128,875	900,243,673.63	0.642
2,013	655,770,135	906,377,060.10	0.724
2,014	651,577,557	941,259,482.89	0.692
2,015	650,379,115	977,413,408.09	0.665
2,016	651,705,004	1,011,183,624	0.644
2,017	655,160,935	1,010,878,387	0.648
2,018	741,397,231	1,010,601,367	0.734
2,019	735,509,451	1,035,865,190	0.71
2,020	733,178,729	1,062,483,745	0.69
2,021	733,847,042	1,044,847,458	0.702
2,022	737,044,905	1,035,153,819	0.712
2,023	842,001,287	1,025,516,653	0.821
2,024	833,595,054	1,028,501,302	0.81
2,025	829,483,954	1,031,554,285	0.804
2,026	828,995,103	1,034,682,433	0.801
2,027	831,560,453	1,037,893,264	0.801
2,028	962,392,700	1,041,195,046	0.924
2,029	950,162,791	1,042,295,552	0.912
2,030	943,226,799	1,043,506,108	0.904
2,031	940,758,322	1,044,837,720	0.90
2,032	942,056,386	1,046,302,493	0.90
2,033	1.10517875e9	1,047,913,744	1.05
2,034	1.08775769e9	1,049,686,120	1.04
2,035	1.07690344e9	1,051,635,733	1.02
2,036	1.07159714e9	1,053,780,307	1.02
2,037	1.07096962e9	1,056,139,339	1.01
2,038	1.27539421e9	1,058,734,275	1.20
2,039	1.25103169e9	1,061,588,703	1.18
2,040	1.23485001e9	1,064,728,575	1.16

V. CONCLUSION

1. Based on the simulation results and assumptions that apply in the modeling, shallow groundwater conditions in the Jakarta municipality if no intervention is carried out it will not be able to support the lives of the people in the Jakarta municipality. If intervention is carried out, savings can be made in the use of water so that the volume of ground water will not continue to decline so that it can support the lives of the people of the municipality of Jakarta.
2. System dynamics modeling with the standard "Changing Goals" model can be used to illustrate the causal relationship between the feedback between the amount of clean water availability and clean water requirements. In this model, the availability of clean water is placed as an actual event, while the need for clean water is placed as a target, the difference between the availability of water and water needs as a gap, the change in the gap as a pressure on the target and the corrective action taken against water needs as a corrective action.
3. Adding negative loops as balancing loop) to the standard model "Changing Targets" can be used as an alternative solution to the achievement of predetermined water needs. That is what is meant by developing models and recommendations for water management in urban areas.

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