Dynamic Model of Household Wastewater Management to Reduce the Pollution Load of Biological Oxygen Demand (BOD)

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Abstract- The increase in population and rapid development in various sectors is directly proportional to the amount of waste produced. The high number of residents will result in increased use of clean water, then the increased use of clean water will increase the amount of waste produced. On the other hand, the amount of infrastructure and facilities for managing household wastewater is very limited. The number of family heads who have access to communal scale wastewater treatment is 3,542 households out of 320,656 households in Makassar City or only 1.1% of households that are served by communal wastewater treatment plants. As a result, waste water sourced from household activities, especially those classified as used water or grey water, is channeled directly into environmental media. The purpose of this study was to formulate a model for household wastewater management. The analytical method used to determine the decrease in BOD and the projected reduction in BOD is done using the dynamic model approach. The results showed that the decrease in BOD pollution load through management stages, namely: reduction of wastewater by 7,53%, recycle or reclaim by 48,63%, and reuse of wastewater by 71,28% from unmanaged conditions or bussiness as usual of 409,996.6 tons/year so that the BOD pollution load entering the environment is equal to 28.72%.

Keywords- Dynamic model, household wastewater management, BOD pollution load

I. Introduction

Makassar City is the Capital of South Sulawesi Province with population number of 1,668,314 people and population growth of 1.003% per year [1]. The increase in population and the rapid development in various fields is directly proportional to the amount of waste produced. The high number of residents has an impact on increasing use of clean water, and the increase in the use of clean water can increase the amount of waste water produced. About 80% of the clean water used in the household's daily life is disposed of as waste water [2], [3]. Wastewater generated from household activities or other activities that produce waste water when dumped directly into environmental media has the potential to cause pollution [4], [5], [6].

Domestic wastewater is waste water sourced from households, offices, and commercial activities. This wastewater is the largest source of water pollutants in urban areas. For example in DKI Jakarta it reaches 80% of the total source of water pollution and only 3% of the total wastewater treated before being discharged into the environment [7]. The same is explained by [8], that around 9 million residents of the City of Jakarta produce around 1,300,000 m^3 of waste water per day, and less than 3% of which has been treated before being discharged into the environment. Likewise in Semarang City, as much as 94% of greywater wastewater is discharged into the drainage and 6% is absorbed into the soil [9]. Conditions such as the City of Jakarta and Semarang also occur in Makassar City because of the lack of waste water management facilities and infrastructure. The number of family heads or household who have access to communal scale off-site systems is 3,542 households [10] of 320,656 households in Makassar City [11]. Thus only 1.1% of households are served by communal wastewater treatment plants (WWTP) or have been processing household waste before being disposed of into environmental media. Waste water sourced from household activities, especially those classified as used water (gray water), is channeled directly to the quarterly, tertiary and secondary drainage, and eventually flows into the primary drainage or river flow and enters the sea [12], [13], [14].

Makassar City is divided by primary drainage or flood canal from south to north, where the two ends of the canal are emptied into the sea. The referred canal is the Jongaya Canal in the south which ends at Losari Beach and Panampu Canal in the north which empties into Paotere Beach . The results of monitoring canal water quality at several points in Makassar City indicate that some parameters have exceeded the required standards, specifically fecal coliform and total coliform parameters [15]. The high coliform content in water indicates that water or waters have been polluted by human waste disposal [16], [17], [18], [19], [20], [21].

The construction of the canal was originally designed to drain surface runoff because the topographic conditions were relatively flat (1 to 5 m MSL), so that when the sea water was installed the drainage water could not flow into the sea. Therefore, flood channels are designed to temporarily accommodate surface runoff and after the sea water recedes, the floodgates at both ends of the canal are opened, so that water can flow into the sea. But the conditions that occur at this time are the initial idea of the canal design not being able to function optimally but rather being a place for holding urban waste. The same condition occurs in the city of Jakarta, where the city of Jakarta has its canal network built to control floods but currently has been partially filled with mud and rubbish [8]. Domestic wastewater management is still based on wastewater disposal, supposed to be based on the management and reuse of wastewater [22], [23], [24], [25], [26]. [27], [28], [29].

Wastewater sourced from households consists of feces, urine and used water (kitchen laundry, washing machine, bathroom, etc.). A mixture of faeces and urine is known as excreta, an excreta mixture with toilet rinse water is known as black water, while used water is known as gray water [19]. The management of domestic wastewater in the form of black water is carried out by managing family latrines equipped with cubluk or individual or communal septic tanks [19]. According to [8], that in Jakarta there are more than 1,000,000 septic tanks, but this is not well translated and handled with groundwater that has been contaminated with coliform bacteria from feces. Drainage of septic tank transfers illegally without drainage water lines [30], [31], [32], [33], [34], [35], [36], [37], [38].

Processed wastewater can be utilized according to its designation, for example for fire protection, to refill aquifers [39], irrigating agricultural land for the production of food crops and vegetables, and irrigating fish ponds [40], flushing the toilet, watering the yard, washing the car [41]. In addition, reuse of used water can reduce water pollution. The potential for used water from households is 50 - 80% of total water use, the most common in urban areas for flushing toilets of 30% of water use [41]. The advantages of reusing domestic wastewater are: (a) provision of nutrition, (b) reliability of water supply, (c) contribution to urban food supply, (d) farmer income, and (e) household livelihood [42]. While the disadvantages of reusing wastewater are environmental impacts and health risks. These losses are mostly related to the use of uncontrolled wastewater which causes the spread of pathogens related to excreta, chemicals, and other undesirable components. The negative effects that are often found in soil are salinization, codification, accumulation of heavy metals and various compounds which have a negative impact on agricultural production in the long term. Helminthiases (infections with worm parasites) are recognized as the biggest health risk from the use of wastewater irrigation [43]. The most common helminthiasis is ascariasis, which is endemic in Latin America, Africa, and the Far East. Other diseases related to the use of wastewater include cholera, typhoid fever, shigellosis, gastric ulcer, giardiasis, amebiasis, and skin problems. Biological health risks are more quickly felt while chemical risks require a delay in the onset of disease, such as the effects of chronic toxins or various types of cancer. Secondary risks may also arise from habitat creation to facilitate vector survival and proliferation and subsequent increases in vector-borne distribution disease in the irrigation area.

Reuse of wastewater also has a political aspect as the Singaopre government is very careful to use the word "waste water" and is replaced with the word "used water" in any information conveyed to the public. Likewise "wastewater treatment plants" are renamed "reclamation installations water ". This communicative strategy is part of a master plan to cover the water balance deficit in Singapore by increasing the quality of urban wastewater to water quality [44].

The integration of rainwater harvesting with the management of greywater can contribute to reducing consumption of drinking water, reducing wastewater treatment needs, contributing to economic savings for water users and operators of wastewater treatment systems [45], [46], [47], [48], [49], [50], [51].

This study aims to formulate a model for household wastewater management.

II. RESEARCH METHODE

A. Method of collecting data

The population in this study is households that live along canals that produce waste water that will enter the canal and then enter the coastal waters of Makassar City. Data on socio-cultural aspects that will be obtained from the population are the behavior of household wastewater management which includes the behavior of clean water use, reduction of household wastewater generation, treatment or recycle and disposal or reuse of treated household wastewater. Determination of the sample is done by cluster random sampling [52], which is determining the sample area, then determining the sample of respondents in each area randomly. In this study the "sample area" is households that live along the canals that have treated wastewater using communal WWTP infrastructure.

B. Study Area

Distribution of clusters (area) consists of 5 areas, as follows: 1) one area towards the estuary of the Jongaya Canal, namely Jl. Teluk Bayur WWTP, 2) one area toward the Panampu Canal estuary (Pasar Terong WWTP), 3) two areas at the junction of the Jongaya Canal - Sinrijala - Panampu, namely Rappocini 1 and Bontolebang WWTPs, and 4) in the middle of the Jongaya Canal (Jl Dg. Ngeppe WWTP). Distribution of cluster (area) sampling can be seen in Figure 1.

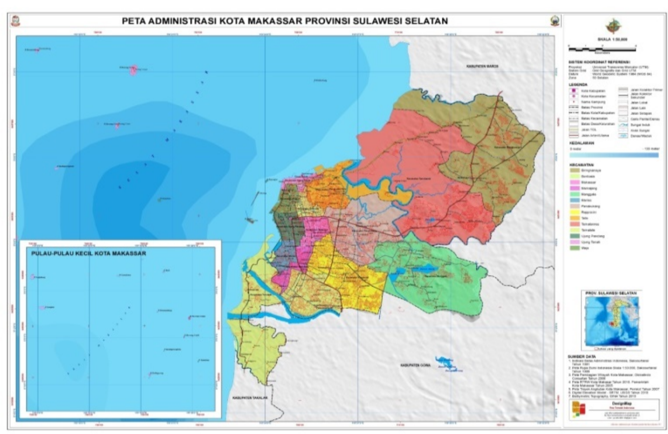


Figure 1. Study area of Research at Makassar City

Determination of samples for technical aspects was carried out by purposive sampling in 5 sample areas. Based on observations in the field, 2 sample areas were selected which had the effectiveness of wastewater treatment that was better than the others. In each of the two sample areas 7 households and 8 households were selected to measure the quantity and quality of household wastewater generated every day.

C. Simulation

This study uses a dynamic model simulation to analyze alternative household wastewater management that can reduce the BOD pollution load into environmental media. Dynamic models are a way of thinking about systems as interconnected networks that influence a number of components that have been determined over time. Simulation is a quantitative procedure that describes a process by developing a model and implementing a series of planned trials to predict process behavior over time, so that analysis can be carried out for the new system without having to build it or change the existing system, and do not need to interfere with the operation of the system. In general simulations are used for dynamic models that involve multiple time periods [53]. Based on this explanation, a household waste water management model that is suitable for environmental conditions is formulated as the research locus. The data obtained is simulated using the Powersim Studio 10 Academic.

III. RESULT

Several variables from the research results and secondary data used in the simulation model, in detail are presented in Table 1.

Table 1. Variables Used in Model Simulation

Variable	Variable Value	Data Source
Total population	1,668,314 person	[1]
Population growth	1.003 % per year	[1]
Total of family head (KK)	467,405 KK	[1]
Waste water generation (TAL)	90.96 litre/person/day	[54]
BOD fraction of TAL (FBOD)	0.016 kg/person/day	[54]
BOD fraction of wasterwater reduction (FPK BOD)	Decreasing BOD 15%	[54]
BOD fraction of wastewater reuse (FPM BOD)	Decreasing BOD 5%	[54]
BOD fraction of effluent WWTP	0.007 kg/person/day	[54]
Effectiveness of WWTP performance (FK WWTP)	43.75%	[54]
KK that have access to the WWTP	1.235%	[54]
Average WWTP capacity	1.183 ton/years	[10]
Modeling periode	2013 up to 2038	-

A. Sub Model of Use of Clean Water and Waste Water Generation

The population growth of Makassar City averages 1.003% every year. The population of Makassar City in 2013 was 1,647,558 people, in 2017 there were 1,714,659 inhabitants and projected that by 2038 there would be 2,114,451 people. Increasing the population will also increase the use of clean water, then increase waste generation and the amount of BOD content. The simulation results show that the pollutant load of BOD wastewater generation in 2013 was 319,441.73 tons, in 2017 it increased to 332.451.84 tons and projected in the year 2038 will reach 409,966.60 tons. For details, can be seen in Figure 2 and Figure 3.

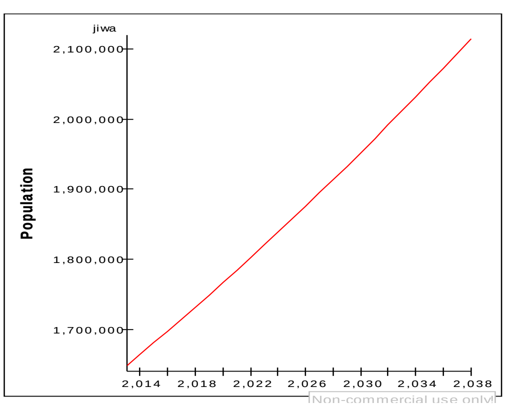


Figure 2. Projection of population growth of Makassar City until 2038

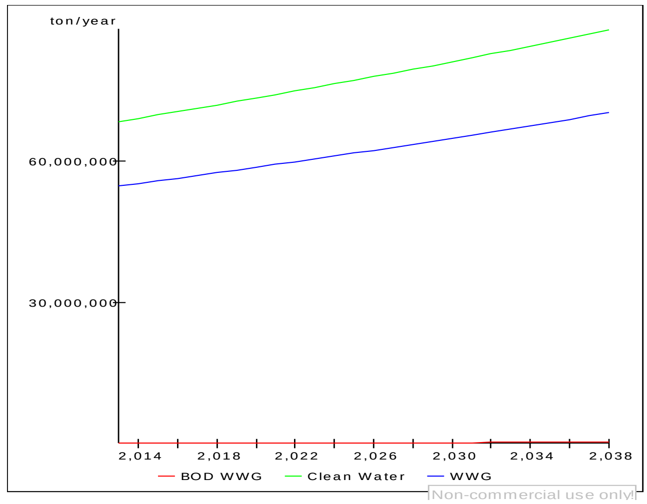


Figure 3. Clean water use, waste water generation (WWG) and BOD pollution load of waste water generation

Validation of the population growth model is done to see the performance of the model. The validation results show that the absolute mean error (AME) value is 0.015 and the absolute variance error (AVE) value is 10.27 or the validation level is good for the BOD sub model load pollution in waste water generation. For details, can be seen in Table 2.

Table 2. Performance validation of sub model the BOD pollution load of waste water generation

Yeasrs	Actual (person)	Simulation (person)
2013	1.647.558	1.647.558
2014	1.652.304	1.664.083
2015	1.653.386	1.680.774
2016	1.658.503	1.697.632
2017	1.668.314	1.714.659
Mean	1.656.013	1.680.941
AME	0.015	
AVE	10.27	

B. Sub model of decreasing BOD pollution load through wastewater reduction

The variables used in the sub-model of decreasing BOD pollution load through reducing wastewater are the reduction of wastewater to flush the yard or streets, water the garden or plants, and flush the toilet. Extension variables are not simulated in reducing wastewater because it will not directly affect the decrease in BOD pollution load, but will only affect the reduction of waste water fractions. For details, can be seen in Figure 4.

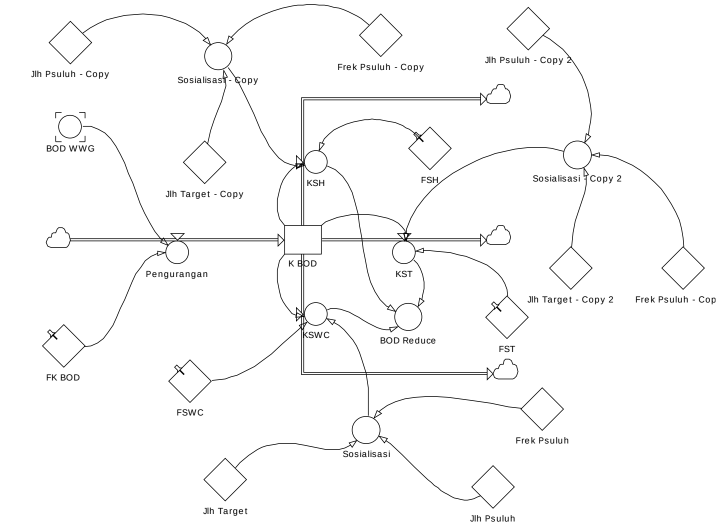


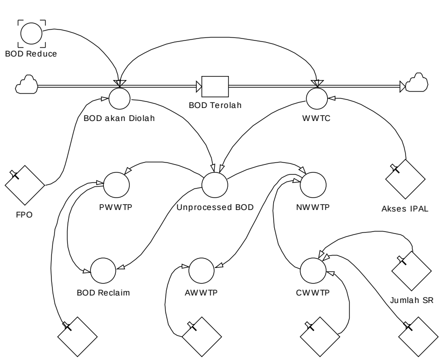
Figure 4. Stock flow diagram of decreasing BOD pollution load trough wastewater reduce

Increasing the population will be followed by increasing BOD pollution load contained in wastewater. Simulation results show that at the end of the year the simulation of BOD pollution load is projected to reach 409,966.60 tons, but the pollution load can be reduced by reusing wastewater for several daily activities, such as flushing toilets, watering plants or parks, watering yards and roads , and used for livestock consumption. The reduction of wastewater by reusing waste water will reduce the BOD pollution load in wastewater [23], [41].

The simulation results of waste water reduction sub model showed that in 2013 the reduced BOD pollution load was 47,916.26 tons, in 2017 it was 155,315.81 tons and at the end of the simulation in 2038 it was projected to increase to 379,122.26 tons. For details, can be seen in Figure 5 and Figure 6.

C. Sub model of decreasing BOD pollution load through waste water treatment

The variables used in the sub-model of decreasing BOD pollution load through wastewater treatment consisted of BOD processing capability, unprocessed BOD, WWTP requirements, IPAL increase, WWTP capacity, and WWTP performance. The inter-variable relationship is described in the stock flow diagram (SFD) of reducing BOD pollution load through wastewater treatment in Figure 7.



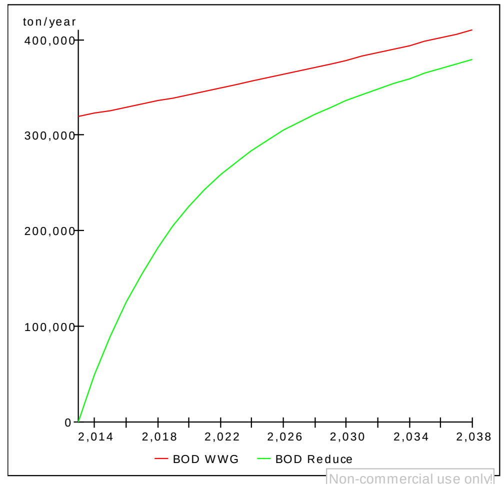
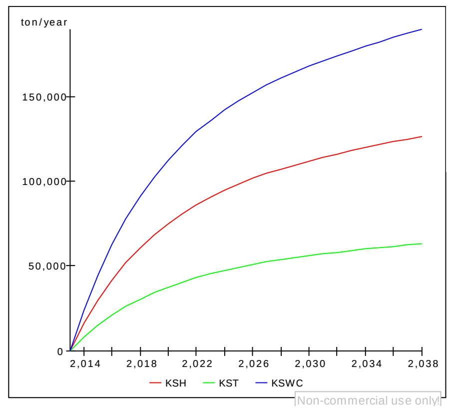


Figure 5. Projections for decreasing BOD pollution load through wastewater reduce



KSH = watering yard or road
KST = watering park or plants
KSWC = flushing

Figure 6. Projections decreasing BOD pollution load through wastewater reduce for watering park, plants, yard, road, and flushing toilet

Figure 7. Stock flow diagram of decreasing BOD pollution load through waste water treatment or recycle wastewater

Increasing population will also increase waste water generation. Increased waste water generation is not accompanied by an increase in wastewater treatment facilities or wastewater treatment plants (WWTPs). Simulation results showed that the processing capacity of wastewater BOD in 2013 was 154.92 tons, increasing to 1,918.15 tons in 2017 and projected at the end of the simulation in 2038 to reach 4,682.16 tons. Unprocessed wastewater BOD load in 2014 was 47,324.49, increasing to 153,397.66 in 2017 and projected at the end of the simulation in 2038 to reach 374,440.10 tons. For details, see Figure 8.

To reduce the BOD pollution load that enters the environmental media, WWTP infrastructure is needed. Based on the data obtained, the average capacity of the communal WWTP that has been operating is only able to treat BOD pollution loads of 1.1826 tons/year per unit WWTP [55]. Thus the number of WWTPs needed in 2014 was 40,017 units, in 2017 it increased to 129,712 units and at the end of the simulation in 2038 it was projected to reach 316,624 units. The government's ability to prepare communal WWTP infrastructure until 2017 is only 131 units or an increase of 0.731% per year. For details, can be seen in Figure 9.

The decrease in BOD pollution load contained in wastewater is largely determined by the performance of WWTP. Based on the data obtained, the performance of communal WWTPs to reduce BOD pollution load in wastewater is 43.75%. The pollution load after processing in WWTP shows that in 2014 amounted to 20,704.47 tons, in 2017 it increased to 67,111.48 tons, and projected at the end of the simulation in 2038 to reach 163,817.54 tons. Waste water treatment carried out can reduce the BOD pollution load in 2014 by 26,620.03 tons, in 2017 it increased to 86,286.18 tons, and projected at the end of the simulation in 2038 to reach 210,622.56 tons. For details, see in Figure 10.

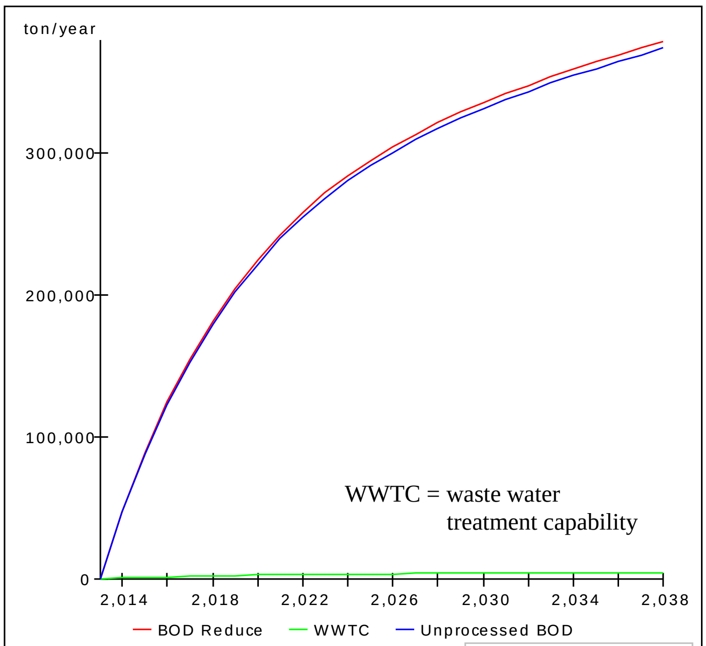


Figure 8. Projected decrease of BOD pollution load through recycle or waste water reclaim

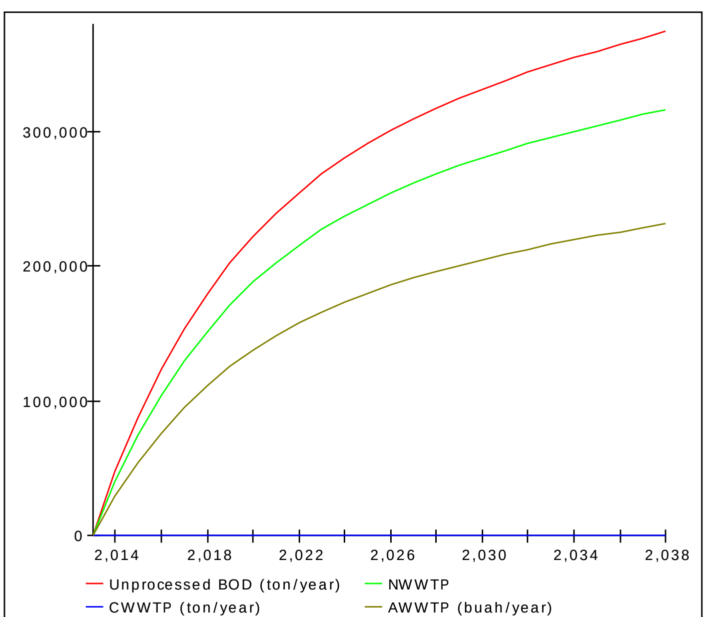


Figure 9. Projected needs and addition of waste water treatment plants to process BOD pollution loads

Where: WWTP = waste water treatment plant; AWWTP = added WWTP (unit/year); CWWTP = capacity of WWTP; NWWTP = need for WWTP

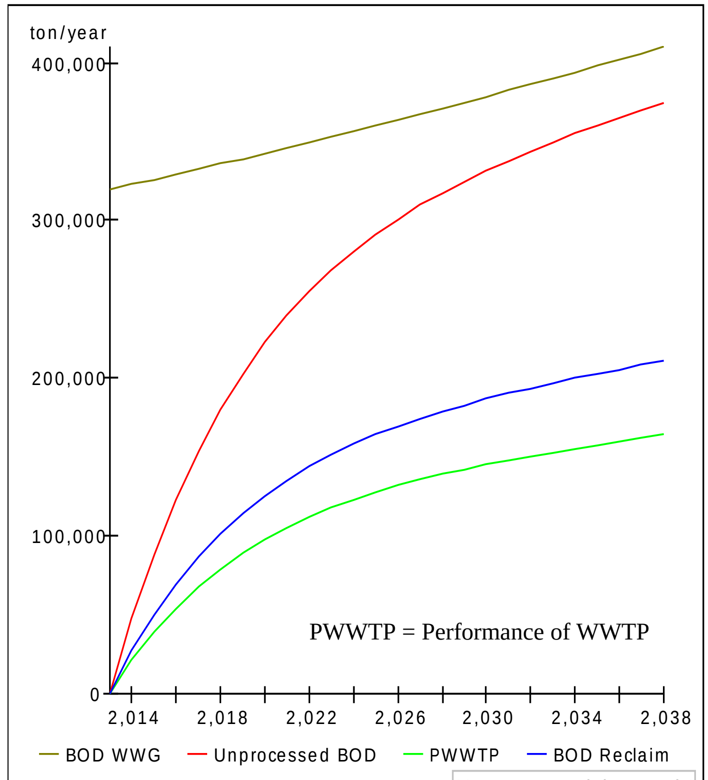


Figure 10. Projected decrease of BOD pollution load after processing using communal WWTP

D. Sub model of decreasing BOD pollution load through waste water reuse

Decreasing BOD pollution load through the use of waste water using variable utilization of wastewater to water the yard or street, watering the garden or plants, filling the fire extinguisher hydrant, injecting it into infiltration wells, BOD entering the environmental media, and counseling. The inter-variable relationship of decreasing BOD pollution load through the utilization of wastewater can be seen in the stock flow diagram Figure 11.

The BOD pollution load that will enter the environmental media even though it has been managed through the stages of reduction, processing and ultimately utilization will continue to increase along with the increase in population. The decrease in BOD pollution load through the utilization of wastewater in 2015 amounted to 1,331 tons, in 2017 it increased to 7,015.33 and at the end of the simulation in 2038 it was projected to reach 117,740.66 tons. Processed waste water that is used to water the yard or street and park or plant is equal in number, namely in 2015 amounting to 665.50 tons, in 2017 it increased to 3,507.66 tons and at the end of the simulation in 2038 it was projected to reach 58,870.33 tons . Waste water that has been treated to date has not been used to fill the fire extinguishing hydrant and injected into infiltration wells. For details, see Figure 12.

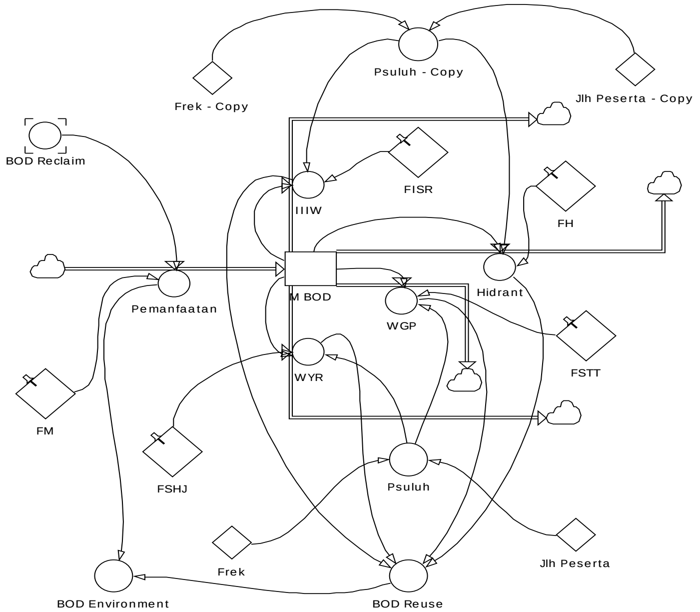


Figure 11. Stock flow diagram of decreasing BOD pollution load through waste water reuse

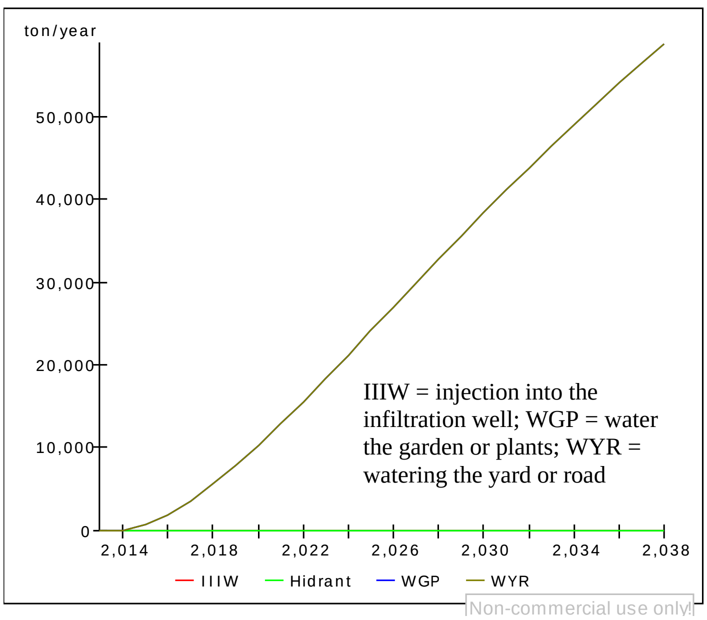


Figure 12. Waste water reuse

The BOD pollution load that enters the environmental media after management (reduction, recycle or reclaim and reuse of watewater) at the start of the simulation in 2013 was 143,304.48 tons, in 2017 it increased to 149,140.94 tons and the final simulation in 2038 was projected to reach 183,914.77 tons. Based on the simulation data, it shows that after waste water management has been carried out a decrease in BOD pollution load of 71.28%. For details, can be seen in Figure 13.

The BOD pollution load has decreased by 71.28% from bussiness as usual or without management, so that the BOD pollution load that will enter the environmental media is 28.72%. The biggest management stage in the percentage of reducing BOD pollution load is waste water treatment that is equal to 48.62%. For details, can be seen in Figure 14 and Table 3.

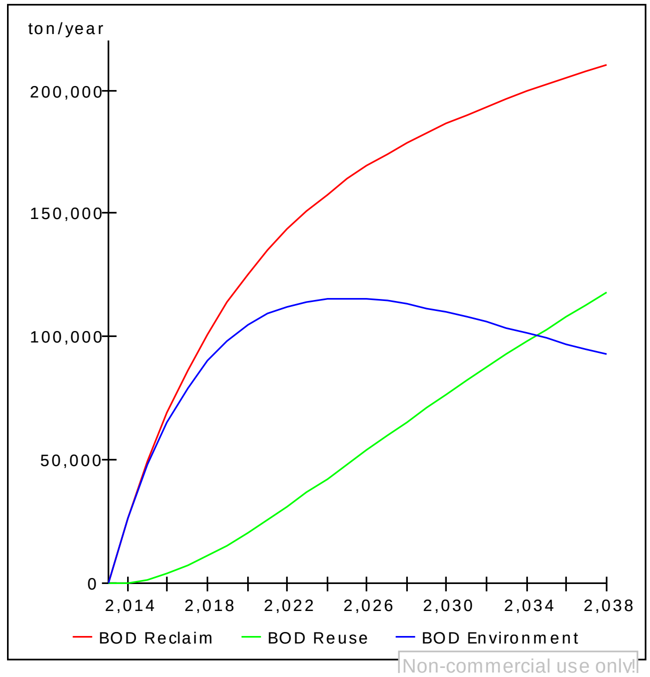


Figure 13. Projected decrease of BOD pollution load through wastewater reuse

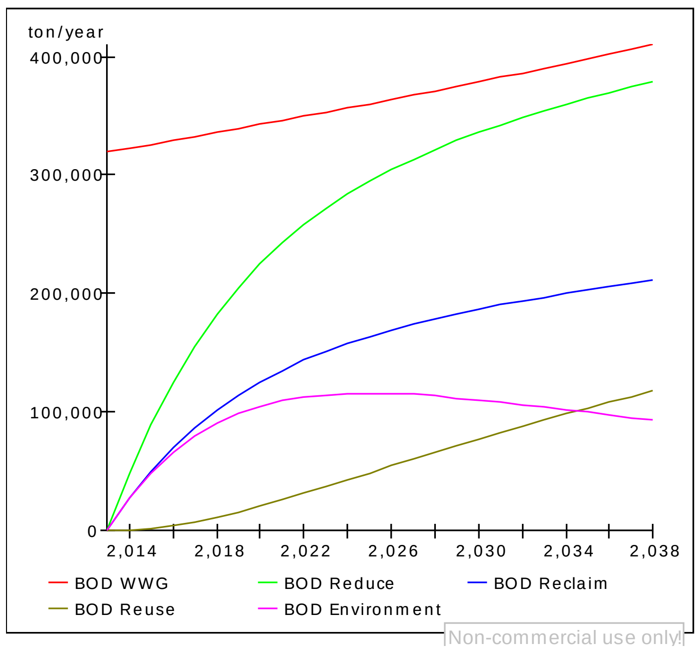


Figure 14. Projected of BOD pollution load that will enter to the environmental media after management

Table 3. Percentage of decreasing BOD pollution load in each management stage

Management stage	BOD pollution load (ton/year)	Percentage	
		Decrease	Accumulation
Without management	409,966.60	-	-
Reduce	379,122.26	7.52	7.52
Reclaim/ recycle	210,622.56	41.10	48.62
Reuse	117.740.66	22.66	71.28
BOD pollution load that enters the environment	92,881.90	28.72	100.00

IV. CONCLUSION

Management of household wastewater to reduce BOD pollution load can be done through the stages of reducing, recycle or reclaim and reusing (3R) wastewater. The reduction in pollution load should be carried out on all domestic wastewater quality parameters.

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