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Drainage management study of the city of Merauke towards inundation by rainfall

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Abstract. One problem that is often faced by the City of Merauke as an urban area is inundation, which disrupts socio-economic activities and damages infrastructure in areas affected by inundation. The aim of this case study is to find ways to deal with inundation that occurs due to rainfall with return periods of 2 years, 5 years, 10 years, and 25 years. The inundation volume for the 2-year return period is zero, for the 5-year return period is 12.58 m^3/sec with a height of 23.35 cm, for the 10-year return period is 18.57 m^3/sec with a height of 25.63 cm, and for the 25-year return period is 20.22 m^3/sec with a height of 27.75 cm. With the Microsoft Excel application, hydrological analysis was performed; spatial analysis using Geographic Information Systems (GIS) resulted in a map of the characteristics of the case study area, and with the Storm Water Management Model (SWMM), hydraulics analysis was performed on existing drainage channels along with simulated management.

Keywords: Rainfall, Inundation, SWMM, Management.

1. Introduction

The City of Merauke, with its occurring development, is experiencing problems of inundation in several areas due to rainfall runoff that cannot be accommodated by the drainage channels. In this regard, it is necessary to have good management to overcome the existing inundation [12, 18]. The analysis of these problems can be performed using Geographic Information Systems (GIS) and Storm Water Management Model (SWMM) in order to show the amount of inundation that must be managed and alternatives for the management [1, 3, 4, 17].

The rate of development of the city in the direction of the rate of population development, every year requires open space which is converted into offices and settlements [2, 5, 6, 9]. With changes in existing land use, affecting the amount of surface runoff that occurs in the area [14, 15]. A reduced

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catchment area will increase the height of standing water at the ground surface due to rain [12]. From statistical data it is known that there was an increase in population from 2010 to 2014 [18].

Dimension of the existing drainage channel is critical, unable to drain the existing runoff water to the river body again. The city of Merauke 50 years ago experienced an inundation as high as one meter, and it has been handled well. But now back inundation occurs everywhere during the rainy season with an average inundation height of 20 cm. The current global climate change is also contributing to the high inundation in Merauke City. Rainfall with low intensity and with a long duration of 4 hours during the rainy season always occurs in each year [18]. The purpose of this study is to what forms of treatment can be done at the city of Merauke drainage so that there is no puddle when it rains.

2. Materials and Methods

This study involved the City of Merauke, covering most of the Mandala Hamlet and a small portion of Samkai Hamlet, with a study area of 390 ha.

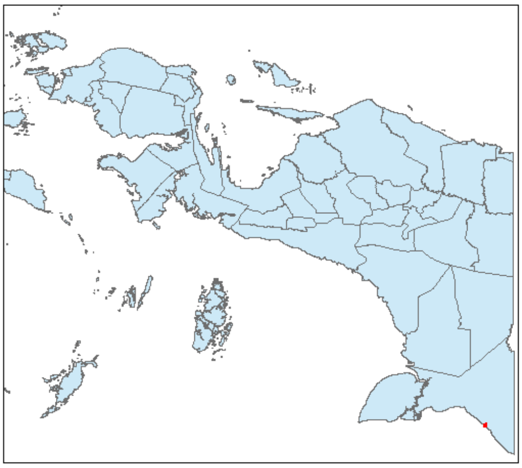

Figure 1. Location of the City of Merauke, Papua.

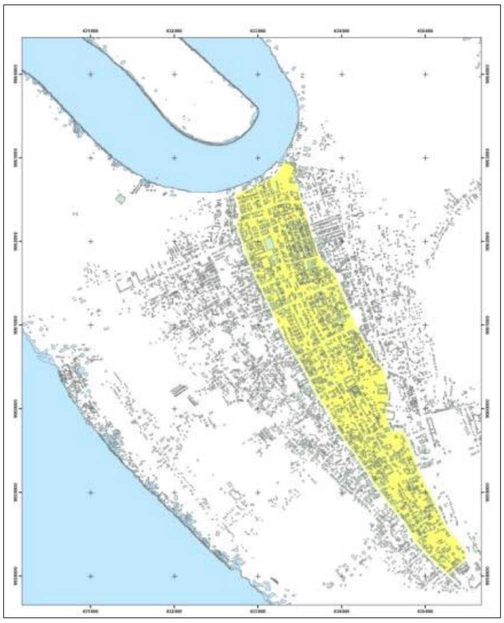

Figure 2. Location of the Study Area.

2.1. Depth of problem

This study does not involve the entire area of the City of Merauke, but is limited to the area from the port to surrounding the Mopah Airport, which has many government facilities in addition to residential areas and is located in the middle of the city.

1. The obtained inundation height was based on rainfall with return periods of 2, 5, 10, and 25 years against existing land use, drainage channels, and topography.
2. In this study, the reviewed existing channel conditions were of the drainage channels that are present.
3. Rainfall data was taken from one station, being the Class III Meteorology Station of Mopah - Merauke.
4. Analysis of the flow profile in the drainage channels utilized the SWMM application.
5. Spatial analysis of land use at the study location utilized ArcGIS.
6. Sedimentation in channels was not included.
7. Water quality was not included.
8. Socio-economic impacts due to inundation were not included.

In this study only two problems will be reviewed:

a) What is the capability of existing drainage in managing inundation due to rainfall with return periods of 2, 5, 10, and 25 years?
b) What should be the treatment for drainage that is not able to bear the burden of inundation due to rainfall with return periods of 2, 5, 10, and 25 years?

By finding out the relationship pattern of rainfall in affecting drainage, the Department of Public Works of Merauke Regency will have a better technical and systematic plan for management of inundation caused by rainfall.

2.2. Theoretical basis

One important matter in hydrological analysis is interpreting the probability of a future event based on hydrological data obtained from past records [13]. For this purpose, the concept of probability is utilized within analysis of hydrological data [7, 8, 10]:

$$P = \frac{1}{T} \tag{1}$$

where:
P = probability (%)
T = return period (years)

To find out the flooding or inundation occurring in an area, the hourly pattern of rain distribution is needed. If the available data are daily rainfall data, rain distribution models can be used to obtain the depth of hourly rainfall from the planned rain [19]. The Alternating Block Method (ABM) is an often-utilized model. The planned Hyetograph that results from this method consists of rain that occurs in a series of *n* consecutive time intervals with duration *Δt* during time *Td* (*Td = n Δt*) [14, 15]. The depth of the rainfall is obtained by multiplying the intensity of the rain by the duration of time (Figure 3).

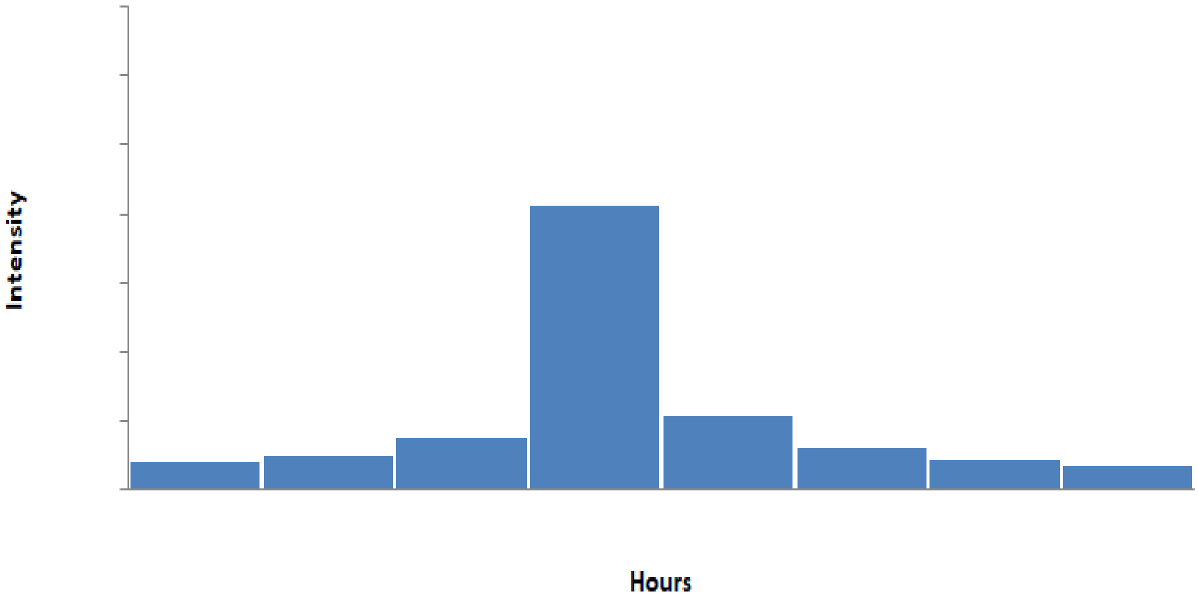

Figure 3. Hyetograph Rain Intensity.

The rational method is one of the oldest methods and was originally utilized only to estimate peak discharge [11]. The following is the basic equation of the rational method [14]:

$$\mathrm{Qp} = \mathrm{C\ I\ A} \tag{2}$$

where:
Qp = Flood peak discharge (mm^3/sec)
C = Flow coefficient
I = Rain intensity (mm/sec)
A = Catchment area (mm^2)

The drainage coefficient of an area of A with various topographic, soil, and vegetation conditions can be calculated by the following formula:

$$C = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i} \tag{3}$$

The infiltration discharge of a shallow infiltration well with the condition that water is absorbed at the bottom of the well is calculated by the following formula [10, 11]:

$$Q_0 = 5{,}5.R.K.H \tag{4}$$

where:
R = well radius (m)
K = soil permeability coefficient (m/sec)
H = water level in the well (m)

The balance of water entering the well and seeping into the soil can be written down as the following formula [12, 13, 14]:

$$H = \frac{Q}{F.K}\left(1 - e^{-\frac{F.K.T}{\pi.R^2}}\right) \tag{5}$$

where:
H = water level in the well (m)
F = geometric factor (m)
Q = incoming water discharge (m^3/sec)
T = flow time (seconds)
K = soil permeability coefficient (m / sec)
R = well radius (m)

2.3. Methodology

This study was conducted with the following steps, the first thing to do is gather information about problems that occur both from the community and related agencies. To be able to find out the causes of the problems that occur during the rainy season, hydrological data, map data and existing hydraulic drainage data are collected. From the data that has been collected, hydrological analysis, map analysis and hydraulics analysis are carried out to find out how much capacity the existing canal has in discharging rainwater flow. Using the help of the SWMM application tool, from the data that has been known, the value of the discharge flowing through the canal is calculated according to rainfall during 2 Years, 5 Years, 10 Years and 25 Years. By comparing the discharge capacity in the channel with the peak discharge due to rainfall in the channel, it is known in which channels that overflow occur and cause inundation in the area. If the channel discharge capacity is greater than the peak discharge, it means that the channel is safe and if the reverse means it requires handling to be safe. For channels that are not safe to channel peak discharge due to rainfall, a treatment plan is carried out with the help of the SWMM application as a simulation tool, so that peak flow through the channel is smaller than the channel's discharge capacity. From the whole description above, it can be concluded what form of treatment is appropriate for the drainage channel (Figure 4).

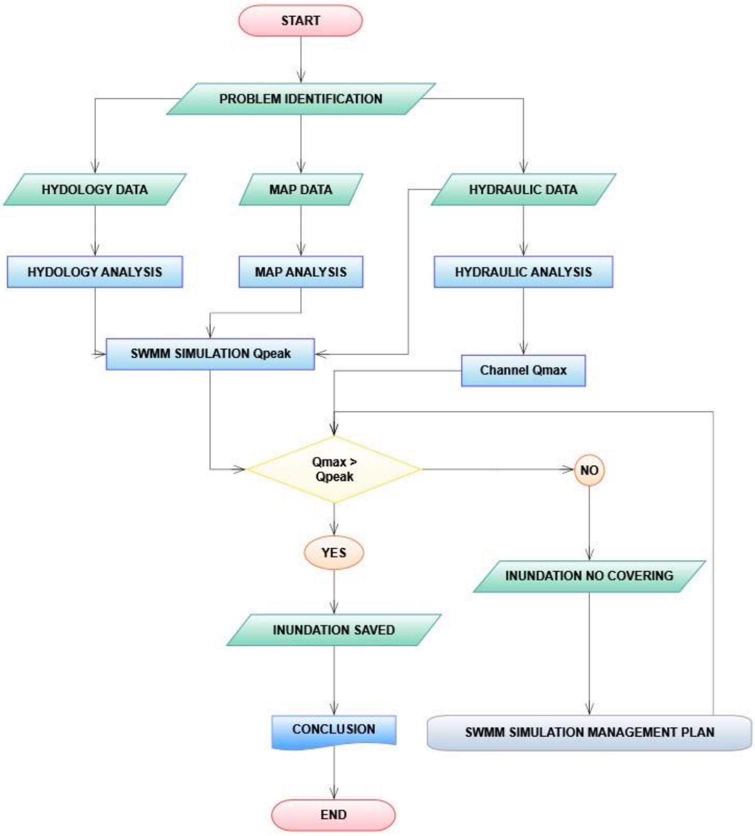

Figure 4. Research Methodology.

3. Results and Discussion

3.1. Existing Conditions of the Study Area

The study area of the research has a variety of land use areas, which are dominated by residential areas, then shops and offices. The study area has a relatively flat topography, with slope variations ranging from 0.2% - 1%. The case study area possesses city drainage channels throughout, but cases of inundation are still found in several surrounding areas.

Table 1. Dimensions of existing channels

Channel	Existing channel (meter)			Channel	Existing channel (meter)			Channel	Existing channel (meter)		
	Wa	Wb	D		Wa	Wb	D		Wa	Wb	D
Sal1	10.8	4	2.9	Sal12	12.8	6	2.9	Sal23	9.8	3	2.9
Sal2	10.8	4	2.9	Sal13	9.8	3	2.9	Sal24	1.5	1.5	1.0
Sal3	10.8	4	2.9	Sal14	2.5	2.5	2.5	Sal25	1.5	1.5	1.0
Sal4	10.8	4	2.9	Sal15	2.5	2.5	2.5	Sal26	1.5	1.5	1.0
Sal5	10.8	4	2.9	Sal16	9.8	3	2.9	Sal27	9.8	3	2.9
Sal6	12.8	6	2.9	Sal17	9.8	3	2.9	Sal28	9.8	3	2.9
Sal7	12.8	6	2.9	Sal18	9.8	3	2.9	Sal29	12.8	5	3.4
Sal8	12.8	6	2.9	Sal19	9.8	3	2.9	Sal30	9.8	3	2.9
Sal9	12.8	6	2.9	Sal20	9.8	3	2.9	Sal31	9.8	3	2.9
Sal10	12.8	6	2.9	Sal21	9.8	3	2.9				
Sal11	12.8	6	2.9	Sal22	9.8	3	2.9				

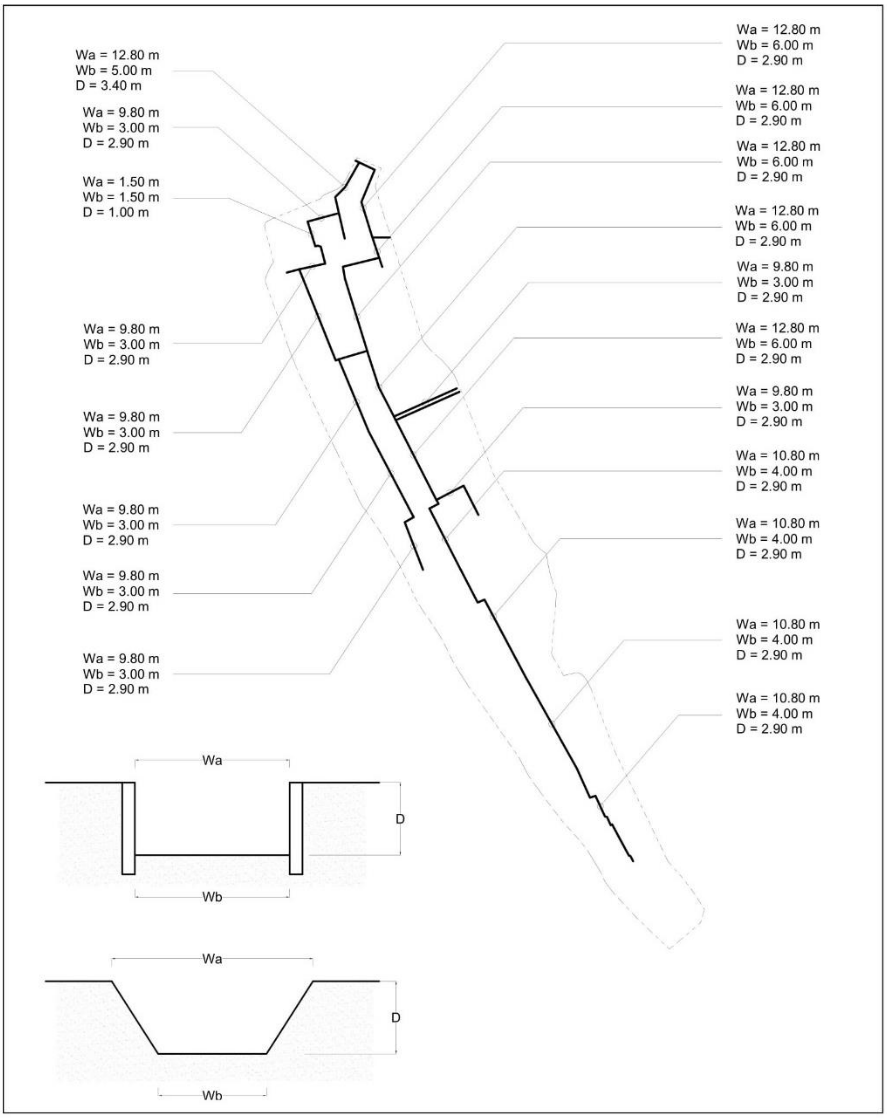

Figure 5. Map of the Drainage Network.

The existing drainage channels have varying sizes and shapes of sections (Figure 5). Some channel sections are trapezoidal and others are rectangular sections, Sal1 to Sal13 are trapezoidal, Sal14 and Sal15 are square, Sal16 to Sal23 are trapezoidal, Sal24 to Sal26 are square, and Sal27 to Sal31 are trapezoidal (Table 1).

By hydrological analysis with daily rainfall data for 20 years, the maximum rainfall with return periods of 2, 5, 10, and 25 years were found. The duration of the return period has a linear relationship with the maximum rainfall that occurs. From the maximum rainfall for each return period, with the Alternating Block Method (ABM), input data was obtained in the form of planned rainfall, which is distributed in the form of hourly rain depths in the hyetograph.

The existing condition of the study area with rainfall of a 2-year return period (117.92 mm/day) was safe, with no inundation and zero inundation volume; with rainfall of a 5-year return period (165.19 mm/day), inundation occurred with a volume of 12.583 m^3/sec; with rainfall of a 10-year return period (200.18 mm/day), inundation occurred with a volume of 18.571 m^3/sec; and with rainfall of a 25-year return period (248.58 mm/day), inundation occurred with a volume of 20.215 m^3/sec. The amount of runoff varied according to the return period, with the runoff becoming greater as the value of the rainfall return period becomes greater.

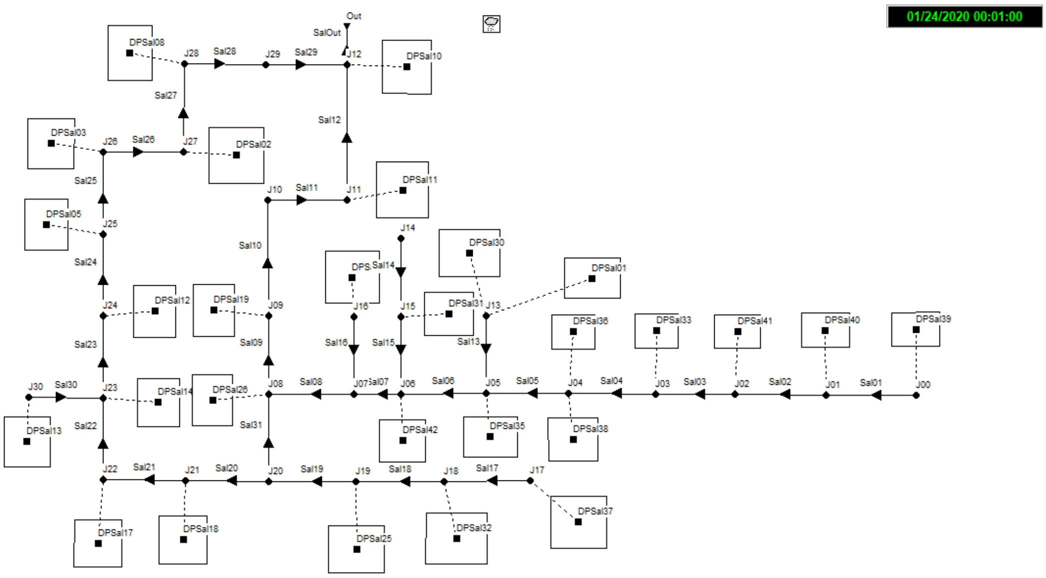

Figure 6. Modeling of Sub-Catchment Areas, Junctions, and Conduits in the Study Area.

From the data collected, in the form of existing hydraulic conditions in the field in the case study area of the existing network system is modeled in the SMWW application (Figure 6). Through the SWMM application, runoff was found in some channels due to rainfall of various return periods as the peak discharge exceeded the channel capacities.

a) With rainfall of a 2-year return period (117.92 mm/day), all drainage channels were safe and none of them overflowed.
b) With rainfall of a 5-year return period (165.19 mm/day), there was overflow at Sal9 = 3.127 m^3/sec, Sal10 = 2.752 m^3/sec, Sal11 = 2.492 m^3/sec, Sal12 = 3.550 m^3/sec, Sal24 = 0.078 m^3/sec, Sal25 = 0.258 m^3/sec, and Sal26 = 0.326 m^3/sec.
c) With rainfall of a 10-year return period (200.18 mm/day), there was an overflow at Sal5 = 0.233 m^3/sec, Sal7 = 3.427 m^3/sec, Sal9 = 3.708 m^3/sec, Sal10 = 2.931 m^3/sec, Sal11 = 2.504 m^3/sec, Sal12 = 4.523 m^3/sec, Sal24 = 0.146 m^3/sec, Sal25 = 0.466 m^3/sec, and Sal26 = 0.633 m^3/sec.
d) With rainfall of a 25-year return period (248.58 mm/day), there was overflow at Sal5 = 0.233 m^3/sec, Sal7 = 3.608 m^3/sec, Sal9 = 4.232 m^3/sec, Sal10 = 3.074 m^3/sec, Sal11 = 2.518 m^3/sec, Sal12 = 5.172 m^3/sec, Sal24 = 0.155 m^3/sec, Sal25 = 0.507 m^3/sec, and Sal26 = 0.716 m^3/sec.

3.2. Management

The problem of inundation occurs in the upstream area, and therefore, management is carried out only in the upstream area, by changing the cross section of the channels and placing wells in areas along the channels that are unable to accommodate runoff.

a. Reduction of inundation volume with infiltration wells [16], with retaining walls placed on channel walls.

It appears that overflow of water flow in several channels due to peak discharge due to rainfall exceeds the channel discharge capacity in channels Sal7, Sal9, Sal10, Sal11, Sal12, Sal24, Sal25 and Sal26 (Table 2).

Table 2. Summary of Channel Capacities for Discharge

Channel	Existing Q_{max}	Rainfall Return Period			
		2	5	10	25
Sal1	33.304	2.104	3.145	3.948	5.090
Sal2	33.304	3.046	4.503	5.627	7.237
Sal3	33.304	5.408	8.029	10.057	13.146
Sal4	33.304	8.535	12.773	16.065	21.540
Sal5	33.304	11.789	17.759	22.418	30.680
Sal6	44.962	14.887	22.568	28.521	40.196
Sal7	44.962	17.539	26.824	33.299	46.230
Sal8	44.962	16.946	25.840	32.531	43.754
Sal9	44.962	24.726	36.542	45.568	48.381
Sal10	44.962	24.833	36.781	45.919	48.442
Sal11	44.962	24.781	36.693	45.793	47.849
Sal12	44.962	25.573	37.895	47.308	50.511
Sal13	38.215	2.817	4.163	5.178	6.777
Sal14	12.182	0.192	0.831	0.876	0.857
Sal15	12.182	2.142	3.898	3.963	4.388
Sal16	38.215	1.921	2.111	1.985	1.920
Sal17	38.215	1.431	1.987	2.367	3.416
Sal18	38.215	3.896	5.483	6.643	9.560
Sal19	38.215	5.313	7.428	9.000	13.181
Sal20	38.215	3.218	4.072	4.551	7.990
Sal21	38.215	1.782	2.221	2.427	3.924
Sal22	38.215	0.963	1.204	1.286	1.578
Sal23	38.215	0.362	0.528	1.297	2.282
Sal24	1.877	0.084	0.835	1.590	1.912
Sal25	1.877	0.241	1.032	1.828	2.385
Sal26	1.877	0.311	1.132	1.951	2.594
Sal27	38.215	0.597	1.537	2.447	3.386
Sal28	38.215	0.991	2.097	3.130	4.505
Sal29	72.618	1.215	1.848	2.828	4.455
Sal30	38.215	0.550	1.270	2.115	3.394
Sal31	38.215	7.964	10.750	12.621	21.225

Maximum discharge of the channel ($Q_{capacity}$) = 44.692 m^3/sec; Discharge due to rainfall ($Q_{rainfall}$) = 46.524 m^3/sec; Inundation volume due to rainfall ($Q_{inundation}$)

$$
\begin{aligned}
Q_{inundation} &= Q_{rainfall} - Q_{capacity} \\
&= 46.524 - 44.692 \\
&= 1.562\ m^3/sec
\end{aligned}
$$

Diameter (D) = 1 m; Depth (H) = 2 m; Soil permeability (k) = 9.21 x 10^{-7} cm/sec = 9.21 x 10^{-9} m/sec; Flow time (T) = 1 hour = 3600 seconds; Form factor (F)

$$\begin{aligned} F &= 5.5 \text{ x } R \\ &= 5.5 \text{ x } \left(\frac{1}{2}\right) \\ &= 2.75 \text{ meters} \end{aligned}$$

Volume that can be absorbed by one well (Q_{abs})

$$\begin{aligned} Q_{abs} &= \frac{F.K.H}{\left(1-e^{-\frac{F.K.T}{\pi.R^2}}\right)} \\ &= \frac{2.75 \text{ x } (9.21\text{x}10^{-9}) \text{ x } 2}{\left(1-e^{-\frac{2.72 \text{ x } (9.21 \text{ x } 10^{-9}) \text{ x } 3600}{\pi \text{ x } 0.5^2}}\right)} \\ &= 0.00044 \text{ m}^3/\text{sec} \end{aligned}$$

Needed number of wells (N)

$$\begin{aligned} N &= \frac{Q_{inundation}}{Q_{abs}} \\ &= \frac{1.562}{0.00044} \\ &= 3551 \text{ wells} \end{aligned}$$

To overcome the overflow in the drainage channel, Sal7 needed 3551 wells, Sal9 required 2481 wells, Sal10 required 3176 wells, Sal11 2254 wells, Sal12 8863 wells, Sal24 required 87 wells, Sal25 needed 1157 wells, and Sal26 needed 1628 wells. It can be seen that the number of wells needed is relatively large, due to the large absorptive capacity of the land in the city of Merauke, other handling methods are needed to resolve the problem above.

b. Reduction of inundation by turning channels into long storage [16], by closing water gates to prevent intervention from the tides of the Maro River. Water is held to the channel capacity limits in the upstream, and the excess is channeled downstream; if the channels in the downstream are full, using a pump with a rate of 5 m^3/sec, the water is discharged into the Maro River.

The Cover Dam on the channels utilizes a spillway or weir: Weir Length (L) = 1 meter; Weir Height (H) = 0.20 meters; Length of channel (L_{sal}) = 2192.67 meters; Channel cross-sectional area (A_{sal}):

$$\begin{aligned} A_{sal} &= \left(\frac{Wa+Wb}{2}\right) \times D \\ &= \left(\frac{10.8+4}{2}\right) \times 2.9 \\ &= 21.46 \text{ m}^2 \end{aligned}$$

The volume of water that can be accommodated by the channels as Long Storage (V_{stor})

$$\begin{aligned} V_{stor} &= L_{sal} \times A_{sal} \\ &= 2192.67 \times 21.46 \\ &= 47054.70 \text{ m}^3 \end{aligned}$$

The storage volume of 47,054.70 m^3 is greater than 36,792 m^3, and thus the channels functioning as storage can safely accommodate the existing discharge. Discharge flowing in the spillway or weir (Q_{we}):

$$
\begin{aligned}
Q_{we} &= C \times L \times H^{\frac{3}{2}} \\
&= 3.33 \times 1 \times 0.2^{\frac{3}{2}} \\
&= 0.298\ \mathrm{m^3/sec}
\end{aligned}
$$

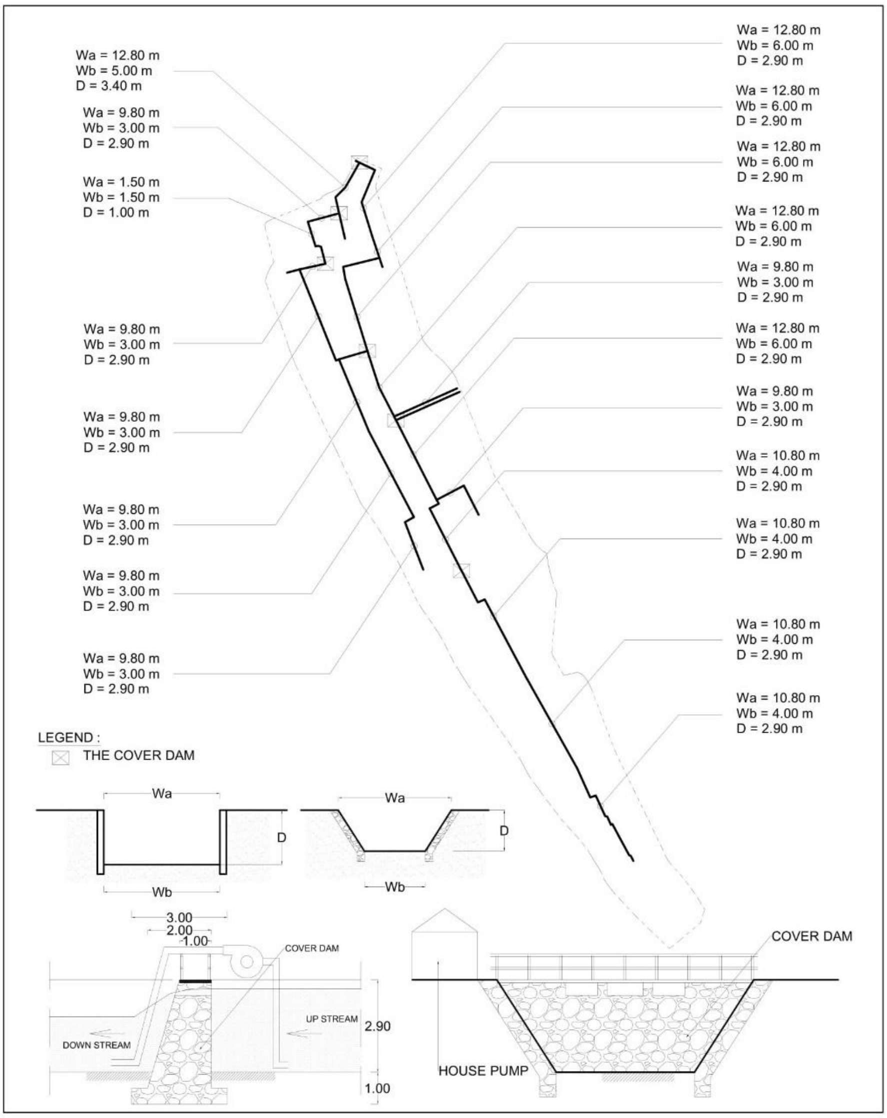

Figure 7. Map of Management Plan with Channels as Storage.

The treatment plan is modeled into the SWMM Application and then executed to check the volume of the peak discharge in each channel.

The results of executing modeling in the SWMM application by placing the cover dam at several points according to the plan, along with the 5 m^3/sec pump to aid in storage draining, are shown in the following table; peak discharge that exceeds the channel capacity was not indicated.

The burden of downstream water flow seems large because it carries the burden from upstream, seeing the capacity of the channel that is in the upstream there is a large discharge difference. By installing

Cover Dam at points 04, 06, 08, 23, 24, 29, the volume of water is held back for some time, not directly flowing from upstream to downstream. In cover dam construction, overflow is installed with an overflow to dispose of water volume that exceeds the channel storage capacity (Figure 7).

Problems that occur on channels Sal5, Sal7, Sal10, Sal11, Sal12, Sal24, Sal25 and Sal26 can be solved properly using this method, for the dimensions of the channel with handling and at which control points that need to be installed cover dam (Figure 7).

4. Conclusion

From the results of the analysis, it can be concluded for the study area that for rainfall, the existing drainage channel is able to accommodate the flow load of rainfall with a 2-year return period and there is no inundation, but for rainfall with 5-year, 10-year, and 25-year return periods, there is inundation. The inundation volume for a 5-year return period is 12.58 m^3/sec with a height of 23.35 cm, for a 10-year return period is 18.57 m^3/sec with a height of 25.63 cm, and for a 25-year return period is 20.22 m^3/sec with a height of 27.75 cm.

The inundation caused by rainfall can be managed by utilizing drainage channels as long storage. At the outlet point, when the rain falls, the gate is to be fully closed to make it easy to control the flow of water due to rainfall and prevent interference from the tides of the Maro River. The water from the upstream should be retained as much as possible first to prevent exceeding the capacity of the channel, by installing a cover dam with a pump of 5 m^3/sec capacity. When the water in the Maro River recedes, drainage channels from upstream to downstream are then drained with the help of a pump.

The construction of water structures in the City of Merauke requires materials to be brought in from other regions since there are no available local materials, making it expensive. The existing problem cannot be resolved within one term of office (5 years) of the regional chief; it must be worked on continuously from the period of one chief to the next. The policy direction of the central government in making the City of Merauke the Capital of the Province of South Papua needs to be followed up with the development direction for the area to minimize the risk of failure of water structures. This means that anticipation of the cause of city flooding must refer to a large planned value, with usage of the 25-year return period among the four periods examined in this study for handling floods.

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