International Journal of GEOMATE, July, 2018 Vol.15, Issue 47, pp.66-73
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2018.47.68850
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

STUDY OF PUMP AND RETENTION BASIN REQUIREMENT FOR SEMARANG-DEMAK COASTAL DIKE PLAN, CENTRAL JAVA

* Andojo Wurjanto[1], Julfikhsan Ahmad Mukhti[2] and Hijir Della Wirasti[3]

[1,2] Ocean Engineering Program, Institut Teknologi Bandung, Indonesia;
[3] PT Dinamaritama Konsultan Rekayasa, Indonesia

*Corresponding Author, Received: 8 Dec. 2017, Revised: 28 Dec. 2018, Accepted: 20 Jan. 2018

ABSTRACT: Semarang city in East Java, Indonesia, is frequently inundated on its northern side due to coastal flooding which is mainly caused by land subsidence. A study by the government to prevent this coastal flooding was started in 2014 and resulting comprehensive solution that ultimately will make 8 km of Semarang coastal area protected by the coastal dike. This leaves the area behind the coastal dike as a polder and hydraulic analysis is critical to ensure the polder areas will not be flooded when extreme rainfall occurs in the area. This study analyses the pumping capacity and retention basin configurations based on the official watershed agency (BBWS Pemali Juana) by performing hydraulic simulations and the result shows that the current configuration is relatively minimalist compared to the solutions suggested to other urban areas in the world. Recommended pump and basin configurations with higher flood-draining performance are given in this study based on the past design experience from the capital city of Jakarta as well as similar cases from other urban areas.

Keywords: Hydraulics, Pump, Semarang, Coastal Dike, Flood

1. INTRODUCTION

The northern coast of Semarang has been vulnerable to coastal flooding, or locally known as 'rob', since around late 1980's. The flood is mainly caused by the high rate of land subsidence which was observed up to 8 mm/year [1]. One of the recent notable disruption caused by the flood was in June 2016 in Kaligawe Semarang Northern Coast Road, in which the traffic was on the peak due to the upcoming Eid al-Fitr Day. The flood was successfully avoided around the Kaligawe Road in 2017 by the installation of pumps. However, the flood still occurred in Terboyo Bus Terminal in early June 2017, which is approximately located 400 m from the coast.

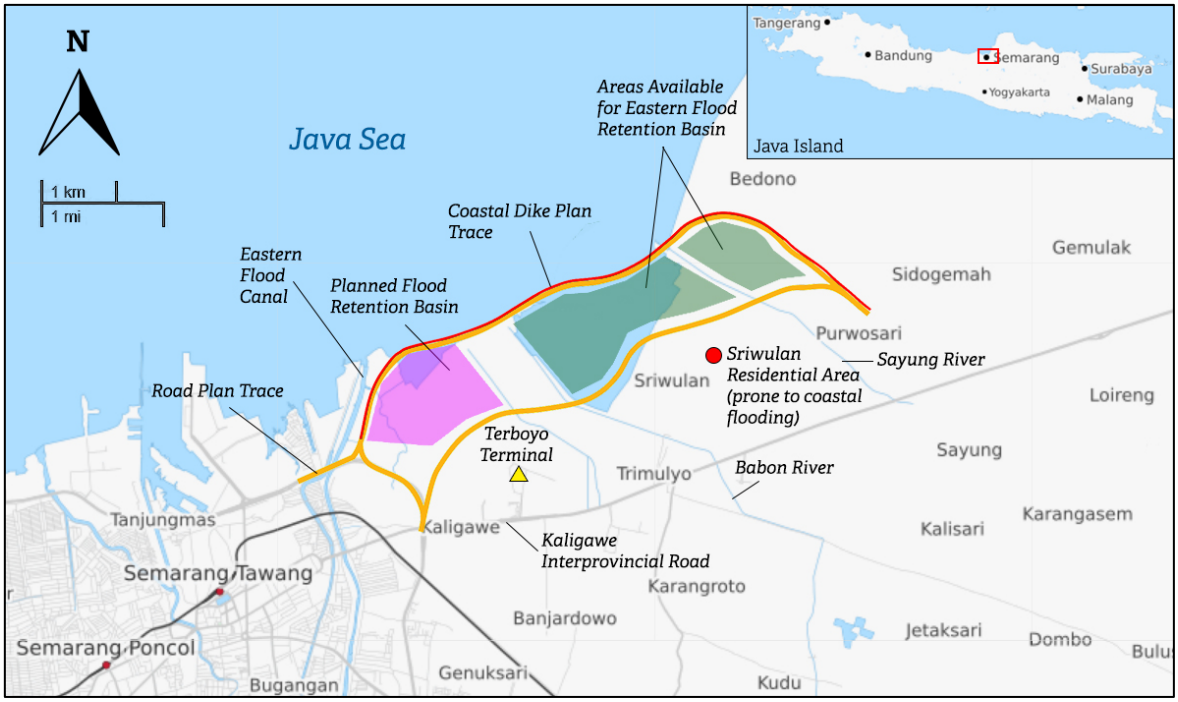
Moreover, during clear weather days, the access road to Terboyo Bus Terminal and residential areas along the Northern Coast such as Sriwulan Village are still inundated during high tide. Houses around the Sriwulan Village are either modified to adapt with the tides by raising the ground floor level or completely abandoned, especially if the footing of the house is still below the water level during the low tide, as shown in Fig. 1.

In 2014, the government started a study to partially overcome this flood problem by having an integrated solution including (1) creation of a flood retention basin, (2) set up a new pump system, (3) normalization of rivers, and ultimately (4) build a coastal dike [2]. This solution will effectively make a part of the northern coast of Semarang as a polder, an approach currently being worked for the National Capital City of Jakarta known as National Capital Integrated Coastal Development (NCICD) [3].



Fig.1 Several regularly inundated areas in the Semarang area, including (1) access road in Terboyo Terminal, (2) access road to Sriwulan Village, (3) Sriwulan Village, in which some of the houses have been abandoned due to the inundation. The water level, according to the local residents, may go up to the road level at least once a month as indicated by the red line shown in (4). Photos were taken on May 23, 2017

The dike was initially planned to be built from Semarang Eastern Flood Canal ('Kanal Banjir Timur') to Terboyo Industrial Area. In early 2017, The Minister of Public Works and Housing announced that the Semarang coastal dike plan



Coastal dike trace and river flow source: BBWS Pemali Juana [4]
Fig.2 Semarang-Demak Coastal Dike, Toll Road, and Retention Basin Plan

will be integrated with a national toll road in Semarang and Demak coastal area as shown in Fig. 2. This leads to the readjustment of dike trace length and requires further hydrological study and infrastructure needed to avoid any flooding within the polder area since the dike will block more river outlet up to Purwosari area.

The aim of this study is to provide a recommendation of retention basin and pump requirements for the polder areas. The solution is based on two scenarios: the first scenario is to assume the coastal dike to be built based on the available trace information, and the second scenario is to split the flood retention basin area at Babon River which is a major river located in the middle of planned toll road trace. The methods of this study along with the explanations about the coastal dike configuration are presented Section 2 with the initial simulation using existing data presented in the following Section 3. The simulations to achieve the suggested pump and retention basin criteria are shown in Section 4. The discussion about the simulation result and validation is presented in Section 5. Finally, the conclusion of this study is given in Section 6.

2. METHODS

2.1 Source of Data

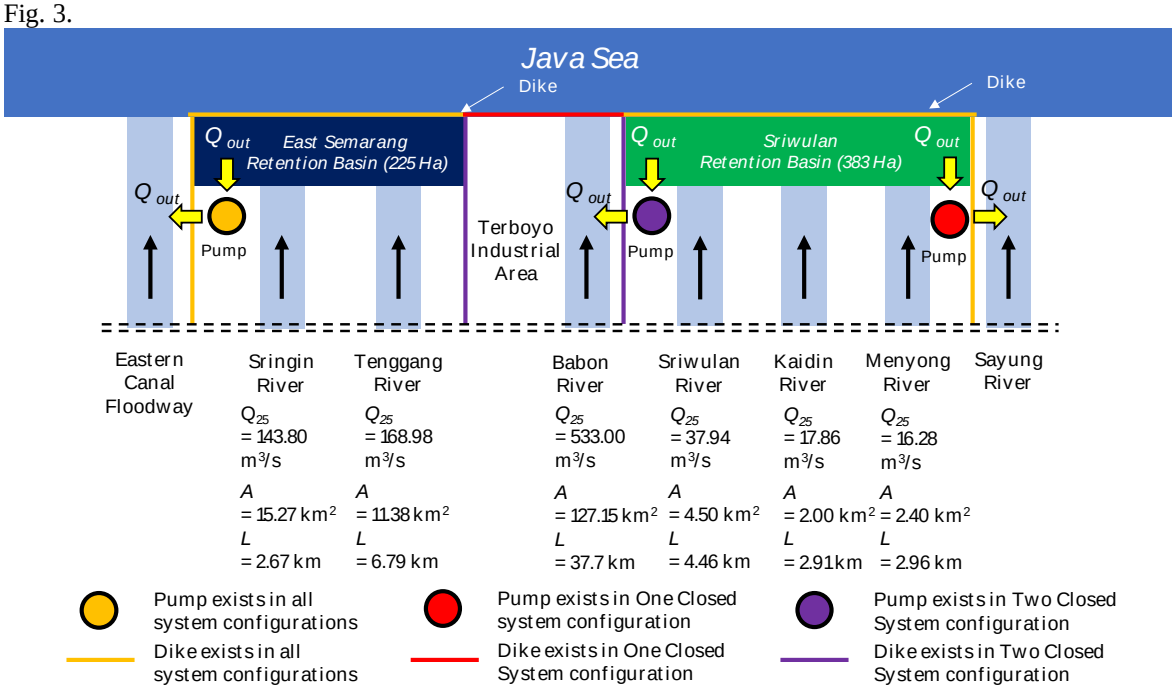
The data used for this study is primarily provided by Pemali Juana Watershed Agency ('Balai Besar Wilayah Sungai Pemali Juana' or 'BBWS Pemali Juana') which consists of (1) planned coastal dike and toll road trace, (2) planned retention basin area, (3) river flow, (4) river scheme, and (5) rainfall.

2.2 Coastal Dike, Retention Basin and Pump Configuration

In this study, the retention basin area is considered as limited to the area between the coastal dike trace and Kaligawe Interprovincial Road. The Planned Flood Retention Basin Area, shown as a purple area in Fig. 2, has been set to 225 Ha by Pemali-Juana Watershed Agency and later referred as East Semarang Retention Basin. The remaining available area within the coastal dike (shown as the green area in Fig. 2), however, has not been officially calculated. Since the remaining available area is dominated by ponds, it is assumed that the area can be fully utilized as retention basin with the total area approximately at 383 Ha. This area is later referred as Sriwulan Retention Basin.

The river flow input into the retention basin is based on the coastal dike configuration. The configuration implied from the coastal dike trace given by BBWS Pemali Juana is to make a one closed-system where the East Semarang Retention Basin receives flow from Sringin and Tenggang River and the Sriwulan Retention Basin receives flow from Babon, Sriwulan, Kaidin, and Menyong River. The river schematics, catchment area A, length L, and 25-year peak river flow Q_{25} amount

for each river of this configuration are shown in Fig. 3.



Coastal dike trace and river flow source: BBWS Pemali Juana [4]

Fig.3 Semarang-Demak Coastal Dike Flow Input Schematics for One Closed System scenario (implied from the coastal dike trace)

However, based on the hydrological analysis done by BBWS Pemali Juana [4], it was implied that the polder will be divided into two closed systems. The first system consists of Sringin and Tenggang River flowing to the East Semarang Retention Basin. The second system consists of Sriwulan, Kaidin, and Menyong River flowing to the Sriwulan Retention Basin. Babon River will be outside of the two closed systems and receives the outflow from Sriwulan Retention Basin pump. This configuration requires the coastal dike to be built up to several kilometers upstream of Babon River and lengthens the dike trace, but will reduce the pump requirement for the second system due to the omission of Babon River from the second system as shown in Fig. 4.

Based on the data from BBWS Pemali Juana [4], it is known that for East Semarang Retention Basin, the planned pumping system consists of three 5 m^3/s pumps and another two 2.5 m^3/s pumps. The Sriwulan Retention Basin is assigned with fewer pumps with only two 5 m^3/s pumps and two 2.5 m^3/s pumps, which is reasonable since the total Q_{25} inflow is significantly lower than in East Semarang Retention Basin. The default configuration for each retention basin is shown in Table 1.

Table 1 Configuration of East Semarang and Sriwulan Retention Basin (BBWS Pemali Juana [4])

Properties	East Semarang	Sriwulan
Pump 1		
Capacity	2.5 m^3/s	2.5 m^3/s
Activation Elev.	-2.1 m	-2.1 m
Deactivation Elev.	-2.6 m	-2.6 m
Pump 2		
Capacity	2.5 m^3/s	2.5 m^3/s
Activation Elev.	-2 m	-2 m
Deactivation Elev.	-2.7 m	-2.7 m
Pump 3		
Capacity	5 m^3/s	5 m^3/s
Activation Elev.	-1.9 m	-1.9 m
Deactivation Elev.	-2.8 m	-2.8 m
Pump 4		
Capacity	5 m^3/s	5 m^3/s
Activation Elev.	-1.8 m	-1.8 m
Deactivation Elev.	-2.9 m	-2.9 m
Pump 5		
Capacity	5 m^3/s	-
Activation Elev.[a]	-1.7 m	-
Deactivation Elev.[a]	-3.0 m	-
Basin Top Elev.	0 m [b]	-1.6 m
Area	225 Ha	40 Ha [c]

[a] The pump activation and deactivation elevation are assumed since there is no available data for the Pump 5.
[b] As provided by BBWS Pemali Juana, the known depth of the basin is 5 m. Therefore, it is assumed that the bottom of the basin is located at -5 m while the top of the basin is at 0 m.
[c] Optimal area in which the water surface elevation will rise exactly up to -1.6 m with given pump configuration based on the simulations by BBWS Pemali Juana [4].

2.3 Rainfall and Hydrograph

Rainfall data is obtained from BBWS Pemali Juana official website [5]. A rainfall data from 2001 to 2010 is used to obtain extreme rainfall with extreme value analyses methods. The calculation result of extreme rainfall analyses is shown in Table 2 with Log-Pearson used for the Q_{25} hydrograph calculation.

Table 1 Extreme Rainfall Analysis Result (in mm)

Return Period	Distribution			
	Gumbel	Normal	Log-Normal	Log-Pearson
2	124	130	144	125
5	156	160	162	162
10	177	176	180	185
25	204	192	197	212

The inflow into the basin is in form of hydrograph with Q_{25} as the peak flow. The hydrograph is made based on Nakayasu Method [6] with formula as follows:

$$Q_d = Q_p \left(\frac{t}{T_p}\right)^{2.4} \quad \text{if } 0 < t < T_p \qquad (1)$$

$$Q_d = Q_p 0.3^{\frac{t-T_p}{T_{0.3}}} \quad \text{if } T_p < t < (T_p + T_{0.3}) \qquad (2)$$

$$Q_d = Q_p 0.3^{\frac{t-T_p+0.5T_{0.3}}{1.5T_{0.3}}} \quad \text{if } (T_p + T_{0.3}) < t < (T_p + T_{0.3} + 1.5\ T_{0.3}) \qquad (3)$$

$$Q_d = Q_p 0.3^{\frac{t-T_p+1.5T_{0.3}}{2T_{0.3}}} \quad \text{if } t > (T_p + T_{0.3} + 1.5\ T_{0.3}) \qquad (4)$$

Where:
L = river length (km)
C = flow coefficient
A = catchment area (km2)
T_p = rain time lag (hour)
= t_g + (0,8 t_r)
t_r = rain concentration time (hour)
= 0.5 t_g
t_g = rain duration unit (hour)
= 0.4 + 0.058 L for L < 15 km
= 0.21 $L^{0.7}$ for L > 15 km
R_o = unit rain (mm/day)
Q_p = peak flow
= (C x A x R_0)/(3.6 x (0.3 T_p+ $T_{0.3}$))
$T_{0.3}$ = Flow decrement time, peak -30%
= α x t_g
α = Hydrograph parameter
= 2.0 for normal flow
= 1.5 for the part of hydrograph which flow rises slowly and falls fast
= 3.0 for the part of hydrograph which flow rises fast and falls slowly (chosen for this study)

The Q_{25} hydrographs generated from the Nakayasu Method is shown in Fig. 4. It is assumed that the floodgates, which exists in Sriwulan, Kaidin, and Menyong River, are open in all water level condition to ensure maximum inflow to the Sriwulan Retention Basin.

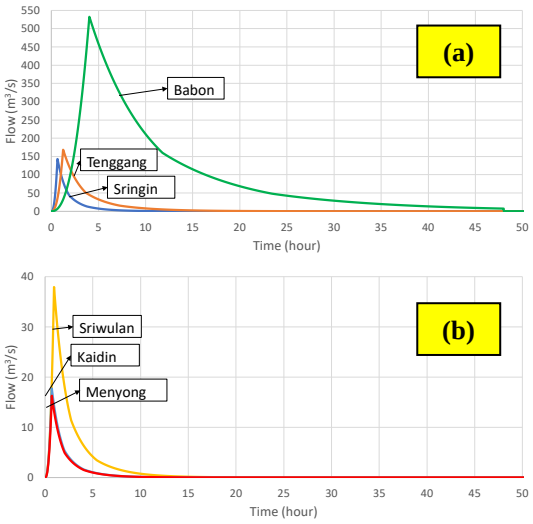


Fig.4 Q_{25} hydrographs generated with Nakayasu Method for (a) Sringin, Tenggang, and Babon River and (b) Sriwulan, Kaidin, and Menyong River

The analysis for determining the pump and retention basin area requirement uses a simple mass conservation method where the change of water elevation Δh in the retention basin depends on the difference between the input flow Q_{in} and output flow Q_{out} for a certain duration t divided by retention basin area A or as written as follows:

$$\Delta h = \frac{(Q_{in} - Q_{out})}{A}\ x\ t \qquad (5)$$

3. INITIAL SIMULATION

Simulation on the BBWS Pemali Juana existing configuration for each basin must be conducted to observe the water surface elevation and pump activity during Q_{25} rainfall. The first

simulation is to simulate the water surface elevation on both retention basins using the BBWS Pemali Juana suggested configuration. A starting elevation of -2.9 m is used as it is the deactivation elevation of Pump 4 of both retention basins, in which the Pump 4 is the pump with lowest known deactivation elevation when the Q_{25} flow enters the basin.

From the simulation result, the pumps on the East Semarang Retention Basin are active for more than 60 hours and the pump on the Sriwulan Retention Basin is active for 24.25 hours as shown in Fig. 5. The simulation by BBWS Pemali Juana [4] also shows over 80 hours and over 24 hours for East Semarang and Sriwulan Retention Basin respectively. This implies that BBWS Pemali Juana allows the pump to be active for over one day in Q_{25} flow scenarios with higher capacity pumps available to operate in case the water level rises higher when a flow over Q_{25} enters the basin or consecutive extreme rainfall occurs.

While this configuration should be adequate to prevent flooding in Semarang area, however, its performance is relatively inferior compared to the retention basin and pump configuration in the capital city. For example, in NCICD case, it is planned that the retention basin for Kamal River in the capital city of Jakarta will have a 90 Ha retention basin with 85 m^3/s pump capacity to prevent flooding caused by Q_{25} flow, in which the Kamal River only has 16.70 Ha of catchment area [7].

4. SIMULATION FOR SUGGESTED CRITERIA

4.1 Proposed Pump and Retention Basin Area Criteria

To improve the retention basin performance, the retention basin area and pump must be reconfigured to achieve acceptable criteria. The proposed criteria of the effective configuration of flood retention basin and pump system in this study are (1) the pumps should not be active for more than 8 hours in one rain event with Q_{25} flow and (2) the maximum increment of water elevation should not be more than 0.5 m above the pump activation elevation. In this study, the proposed effective configuration only uses a single pump with activation and deactivation elevation set on -2.1 m and -2.9 m respectively.

4.2 Simulation for East Semarang Retention Basin

The retention basin area, since it has been determined by BBWS Pemali Juana, is set to be fixed at 225 Ha. East Semarang Retention Basin is also not affected by the coastal dike configuration since the catchment area is limited to the western side of Babon River. Therefore, the only variable in this simulation is the pump configuration. To meet the proposed criteria, it is found that the pump should have the capacity of 85 m^3/s ('Custom Pump A') as shown in Fig. 6.

4.3 Simulation for Sriwulan Retention Basin

For Sriwulan Retention Basin, the variables included are retention basin area, pump capacity, and the coastal dike configuration which will

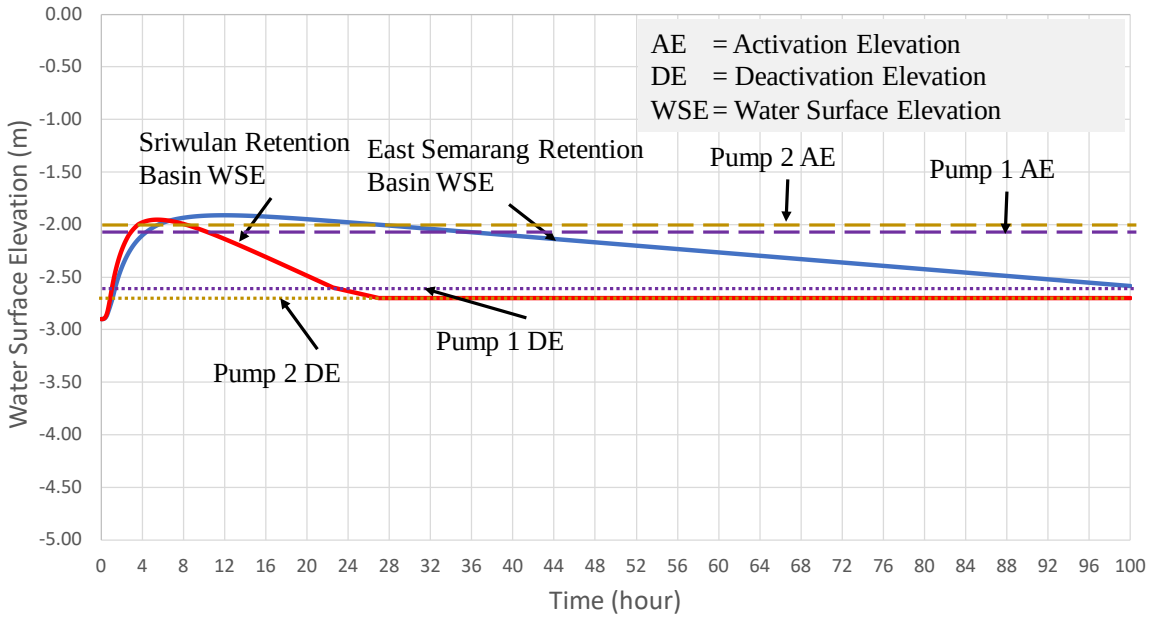


Fig.5 Hydraulic simulation result of Q_{25} hydrographs entering East Semarang and Sriwulan Retention Basin

include or exclude Babon River to the calculation. For two closed-systems configuration and using the suggested retention basin area by BBWS Pemali Juana, the proposed pump capacity is 17 m^3/s ('Custom Pump B'). The retention basin area can also be reduced up to 18 Ha if necessary as shown in Fig. 7. The adjustments on retention basin area do not have any effect to pump active duration in this simulation.

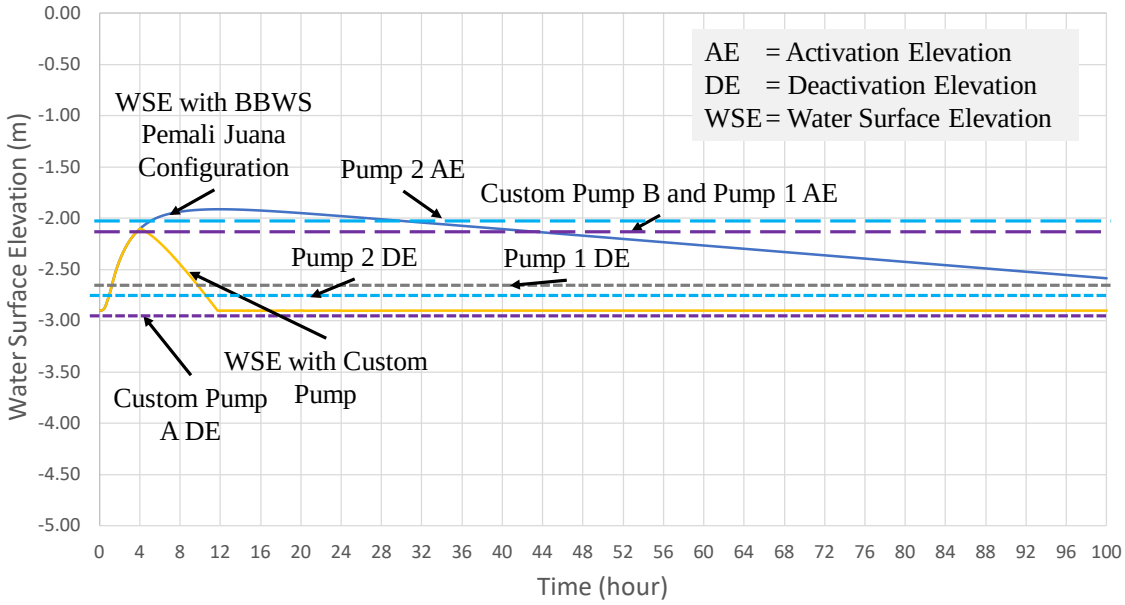


Fig.7 Hydraulic simulation result of Q_{25} hydrographs entering East Semarang Retention Basin with default and custom pumps.

However, when the Babon River is included to the Sriwulan Retention Basin, the pump must be greatly increased to 600 m^3/s ('Custom Pump C') to achieve the proposed configuration. The simulation result for the BBWS Pemali Juana default configuration, two closed-systems with custom pump, and one closed-system with custom pump and full utilization of available retention basin area of 383 Ha is shown in Fig. 8.

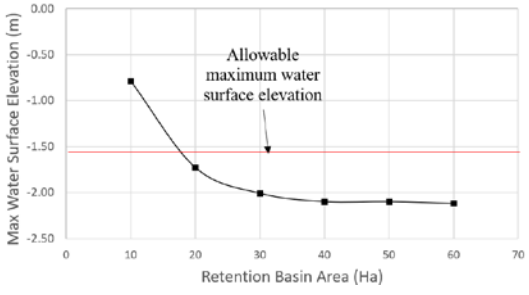


Fig.8 Sriwulan Retention Basin Area utilization compared to maximum water surface elevation due to Q_{25} flow with 17 m^3/s pump on the retention basin.

5. DISCUSSION

The pump configuration from BBWS Pemali Juana for both East Semarang and Sriwulan Retention Basin have been simulated in this study and shows agreement with simulations done by BBWS Pemali Juana as described in Section 3. From the simulation result, it can be concluded that the Q_{25} flow draining performance in East Semarang and Sriwulan Retention Basin is lower than other urban retention basin and pumping configurations. Therefore, the pump capacity needs to be increased for each retention basin.

To comply with the suggested criteria, the pump capacity for East Semarang retention basin is suggested at 85 m^3/s. This capacity is similar to pump capacity suggested for Kamal Area in the capital city of Jakarta [7]. Although the Kamal area has a smaller 19.44 Ha of river catchment area compared to total 26.65 Ha of in East Semarang, the Kamal area also has a smaller provided retention basin area, which is only 90 Ha compared to 225 Ha in East Semarang. Therefore, it is safe to set the pump capacity in East Semarang to the same degree as Kamal.

Pump capacity for two closed-system in Sriwulan is suggested at 17 m^3/s or only 13% higher than the BBWS Pemali Juana suggested configuration. Optimizations to the basin can still be done by reducing the basin area. However, for a long-term purpose, it is recommended that the retention basin area should be increased by using available area instead of being reduced to provide more time for pump repair in times of failure.

For the one closed-system simulation which follows the current coastal dike trace, however, the

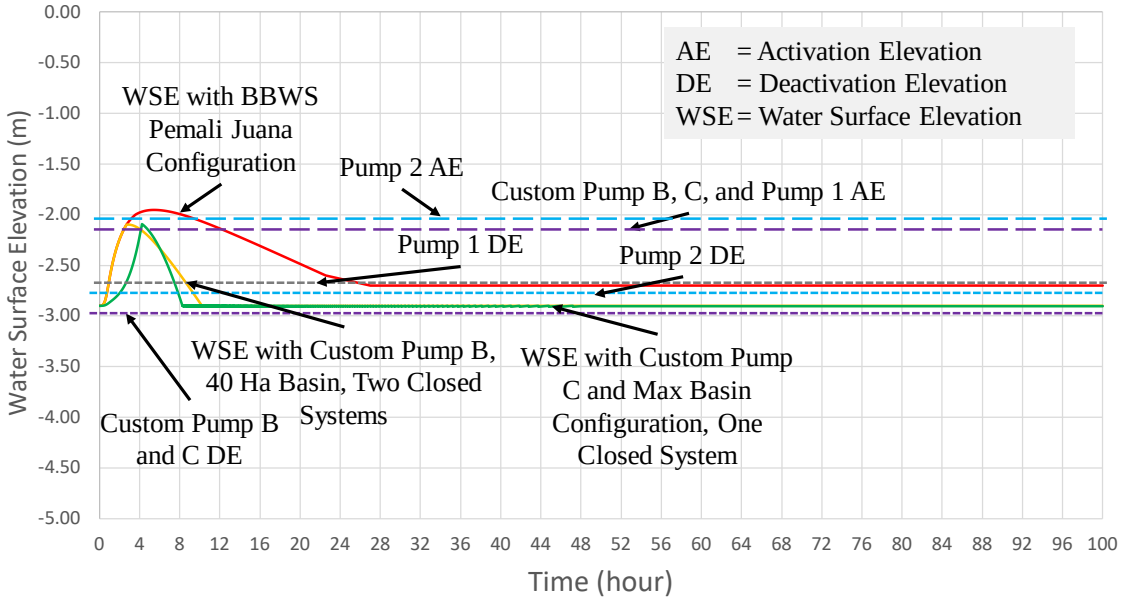


Fig.8 Hydraulic simulation result of Q_{25} hydrographs entering Sriwulan Retention Basin with default and custom configurations.

pump capacity required is an order of magnitude larger than other configurations in this study. This is due to the significantly higher Q_{25} peak flow of Babon River at 533 m^3/s or 7.4 times of Sriwulan, Kaidin, and Menyong River peak flow combined. As a comparison, 600 m^3/s pump capacity means it has 69% more capacity of the largest pumping system in New Orleans [8] or 2.7 times more capacity than the largest pump designed for NCICD project which is located in Marina-Sentiong area [7]. Although the catchment area of East Semarang with Babon River included is considerably higher at 136 km^2 compared to Marina-Sentiong area at 55.62 km^2, based on the experience from 2017 New Orleans flood, pump capacity may diminish, and higher capacity pumps will be more expensive or difficult to be maintained. Considering this concern, it is not recommended to block the Babon River with the coastal dike in the estuary and the currently published trace should be updated accordingly to reflect the current configuration used by BBWS Pemali Juana.

6. CONCLUSION

It has been shown that higher capacity pumps are required in Semarang drainage system to be able to perform on par with the drainage system in the Capital City of Jakarta. The pump capacity should be increased from 20 m^3/s to 85 m^3/s in East Semarang Retention Basin, while the Sriwulan Retention Basin pump capacity only needs to be improved from 15 m^3/s to 17 m^3/s to achieve the desired criteria. The coastal dike trace should also be readjusted according to the latest simulation by BBWS Pemali Juana to prevent public misinterpretation of the trace and currently no cities in the world that have the amount of pump capacity required to block the Babon River by the coastal dike.

In a broader context, simple simulation methods presented in this study can also be used to check the performance of pump schemes in an urban area and compare them to other areas. The inclusion of higher return period flow in the analysis can be beneficial for pump, coastal dike, or river dike improvement is also suggested for future works. As an example, the NCICD project also takes 100-year return period flow Q100 into simulations [7].

7. ACKNOWLEDGEMENTS

This research was funded by P3MI program from Institut Teknologi Bandung. We would also like to acknowledge BBWS Pemali Juana for providing initial design data for study and Ciliwung Cisadane Watershed Agency (BBWS Ciliwung Cisadane) for providing NCICD proposed pump schemes data for comparative study.

8. REFERENCES

[1] Lubis A.M., Sato T., Tomiyama N., Isezaki N., Yamanokuchi T., Ground Subsidence in Semarang-Indonesia Investigated by ALOS-PALSAR Satellite SAR Interferometry, Journal of Asian Earth Sciences, Vol. 40, 2011, pp. 1079-1088, 2010.

[2] Balai Besar Wilayah Sungai Pemali Juana (Pemali Juana Watershed Agency), Pengendalian Banjir Rob Semarang (Semarang Coastal Flooding Control), Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2017, pp. 38-40.
[3] Witteveen+Bos, Grontmij, Ecorys, Kuiper Compagnons, Triple A, & Deltares, Master Plan National Capital Integrated Coastal Development: Engineering Report. Kementrian Koordinator Bidang Perekonomian Republik Indonesia (Coordinating Ministry of Economy, Republic of Indonesia), 2014, p. 86.
[4] Balai Besar Wilayah Sungai Pemali Juana (Pemali Juana Watershed Agency), Detail Desain Tanggul Laut: Tahun Anggaran 2017 (Detailed Design of Coastal Dike: 2017 Budget), Kementerian Pekerjaan Umum dan Perumahan Rakyat (Ministry of Public Works and Housing), 2017.
[5] Balai Besar Wilayah Sungai Pemali Juana (Pemali Juana Watershed Agency), Database [Online], Available: http://www.bbwspemalijuana.com/database, 2017, September 8.
[6] S. Sosrodarsono and K. Takeda, Hidrologi untuk Pengairan (Hydrology for Irrigation), Issue 9, Jakarta: Pradnya Paramita, 1987.
[7] Deltares, Pump Schemes NCICD Phase A Retention, Balai Besar Wilayah Sungai Ciliwung Cisadane (Ciliwung Cisadane Watershed Agency), 2016.
[8] US Army Corps of Engineers, Hurricane & Storm Damage Risk Reduction System: Permanent Canal Closures and Pumps [Online]. Available: http://www.mvn.usace.army.mil/Missions/HSDRRS/PCCP/, 2017, September 10.

Copyright © Int. J. of GEOMATE. All rights reserved, including the making of copies unless permission is obtained from the copyright proprietors.