International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Numerical Modeling of Variation in Spillway Dimensions and Variation in the Shape of Spillway for the Effectiveness of Boezem

Anna Amalia Misdanik[1], Umboro Lasminto[2]
[1, 2]Department of Civil Engineering, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia, 60111

***Abstract*— *The residential area around Boezem Kedurus is often combined with topographic rain compilation, the air in the settlement can be accessed elevation to Boezem. One part contained in boezem is a spillway structure which is a lateral structure that serves to connect channels / rivers with a pool / boezem area. The existing spillway should have been able to increase the effectiveness of the boezem reservoir. Determination of the type of overflow building must consider the geological, topographic, safety, social and economic conditions, methods of operation and maintenance. In building spills a Broad Crested is used as a building to increase the height of the face and determine the air flow. Therefore the selection of the dimensions of the overflow building can affect the speed distribution and distribution of debits that affect the effectiveness of the boezem reservoir. Modeling is done with various dimensions of the width of the width of 10 meters, 20 meters and 30 meters. The type of lighthouse used is the width Broad Crested type and Ogee. At the end of the simulation it can be seen that the larger the dimensions of the overflow width, the greater the discharge obtained. But to determine the effective spill width, an analysis of the Tail Water Stage from Boezem was carried out. Water level reduction in the Kedurus Primary Channel occurs at the most significant amount of 71 cm using a 10 cm spillway width scenario with a wide Broad Crested light. The depth of inundation decreases the fastest with 1 hour using dredged boezem conditions, 30 meter spillway width and Ogee lighthouse type.*

***Keywords*— *Boezem, Spillway Variation, Discharge, Effectiveness of Boezem.*

I. PRELIMINARY

In this modeling, the Boezem Kedurus study area was used. Boezem Kedurus is located in Rayon Wiyung, Surabaya. This Boezem is estuary of the Kedurus Primary Channel. Topographically, this Boezem should also be able to hold water from surrounding settlement. However, the result of the inundation survey in Surabaya in 2017, the settlement is still inundated by around 120 cm with an area 251. 77 hectares.

There are times when the flow from the primary channel or river overflows out the channel body through cliffs or dikes. One of them is caused by changes in land use change so that the channel dimension can no longer accommodate runoff discharge. In addition to silting the channel also occurs due to sedimentation. However, river flows can be designed to overflow into certain reservoirs. This can be done by building a side spillway which is flowed into the reservoir.

On the right side of the primary drainage water channel, there are spills located at the river sta 70.1 and river sta 53.1. river sta is a discretion of the channel that can be shown in figure 1. The existing condition of the spill has width that varies around 10 meters to 30 meters.

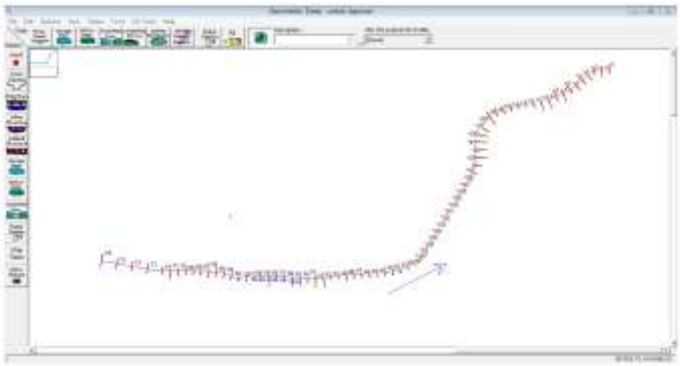

Fig. 1. Discretion of the channel

In this modeling simulation is carried out with variations in spillway location, dimensions, and spillway form used. To see the effectiveness of the Boezem, modeling also was carried out with Boezem condition dredged so as to get a greater storage capacity. It is expected to reduce the face in the primary channel and reduce inundation around the settlement.

II. MATERIAL AND METHODS

A. Materials

The materials used in this modelling are primary and secondary data. The secondary data as follows:

- Rainfall data from 2001 to 2015
- Topographic data on the area of Kedurus
- Rayon Wiyung drainage network data

Meanwhile the primary data consist of:

- Land use map
- Channel flow velocity measurement data
- Channel water depth measurement data

B. Methods

This modelling is made using HEC-RAS 5.0.3 auxiliary program. The stages of this modelling are carried out with the following steps:

a) Preparation stage

Preparation were made with literature studies, field investigations, determining the location of the study.

b) Collecting and Processing Data

- Secondary data processing
  - Carried out hydrological analysis of rainfall data from 2001 to 2015

Anna Amalia Misdanik and Umboro Lasminto, "Numerical Modeling of Variation in Spillway Dimensions and Variation in the Shape of Spillway for the Effectiveness of Boezem," *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 3, pp. 230-235, 2019.

- Processing topographic data into terrain data in the HEC-RAS 5.0.3 model. In addition, topographic data processing is carried out to become a Digital Elevation Model (DEM) data using Global Mapper. By using DEM data, a land use map and channel discretization can be made.

▪ Primary data processing
- Measurement of flow velocity in upstream and downstream channel using a current meter.
- Water depth measurement in the upstream and downstream channel using simple tools of paving stone which is bounded by rope.
- Making land use maps using DEM data with Google Earth auxiliary program.

c) Design discharge analysis

Daily rainfall data is used as annual return period data. Previously, statistical parameter analysis we found the Log Pearson Type III distribution that corresponds to the data.

$$\text{Log } X = \text{LogXrat} + G.S$$

with:

X	: design discharge return period
Log Xrat	: the average of X
S	: standard deviation
G	: coefficient of distribution with Cs and time

d) Calibration

The calibration is done by adjusting the depth of water in the downstream and upstream channel of the measurement result, with the result being modeled. In essence, the purpose of the calibration is to get a channel hydraulic model that is close to the actual condition. Adjustments are made to the manning (n) model values of manning value that are permitted as in the following table.

TABLE I. Permitted of manning (n) value

No	Type of Channel	Minimum	Maximum
1	Regular cross section without stone and thickets	0.025	0.060
2	Irregular and rough cross section	0.035	0.100

C. Scenario Modeling

To achieve the expected research objective, a modeling scenario is needed. Scenarios are based on a number of conditions that are expected to represent field conditions.

D. Hydraulic Modeling

Hydraulic modeling is made using the HEC-RAS 5.0.3 auxiliary program. The model consist of the Kedurus Primary Channel, Boezem Kedurus as a storage area and the surrounding settlement as 2D area.

III. Result and Discussion

A. Modeling scenario analysis

This analysis is done to determine the type of variation of the scenario to be modeled.

▪ Boezem condition analysis

In this analysis there are two types of bezem condition, the existing Boezem and dredged Boezem. The dredged Boezem condition is obtained by changing elevation of the DEM map. Elevation changes are made by making the Boezem as a full storage condition. The lowest elevation and highest elevaton of the Boezem are same in existing or dredged condition.

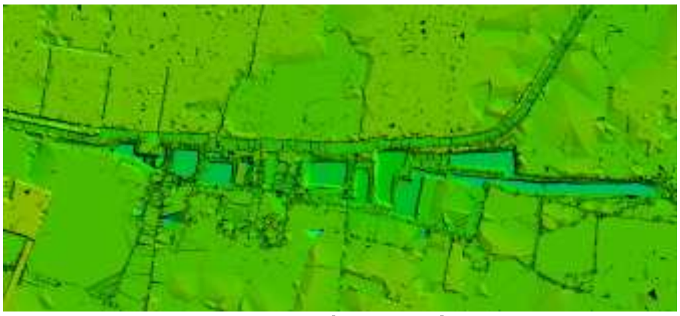

Fig. 2. Existing boezem condition

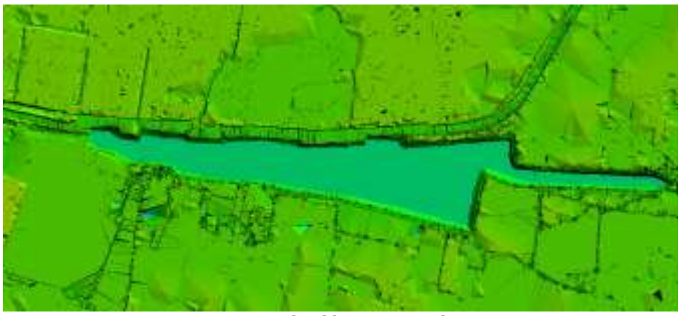

Fig. 3. Dredged boezem condition

To find out the capacity of each Boezem condition, shown in the following curve.

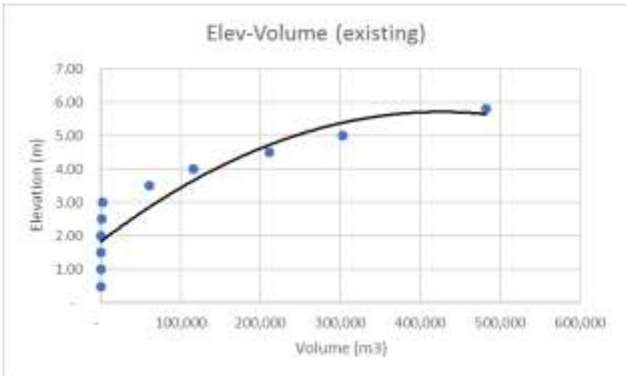

Fig. 4. Curved Capacity of existing Boezem condition

In figure 4, the maximum elevation is +5,8 meter with maximum volume is 481,880 m^3.

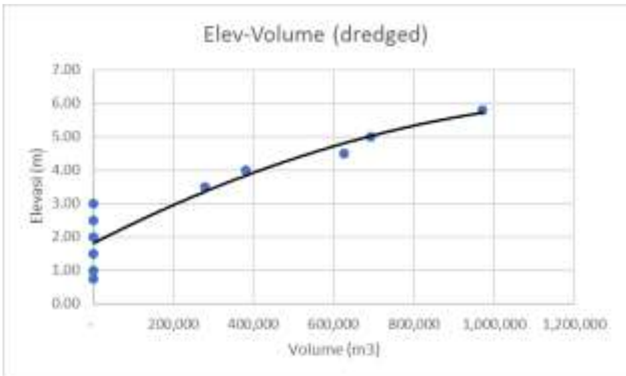

Fig. 5. Curved Capacity of dredged Boezem condition

Anna Amalia Misdanik and Umboro Lasminto, "Numerical Modeling of Variation in Spillway Dimensions and Variation in the Shape of Spillway for the Effectiveness of Boezem," *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 3, pp. 230-235, 2019.

In figure 5, the maximum elevation is +5,8 meter with maximum volume is 972,260 m^3.

- Analysis of spill shape variations

The shape of spillway varied is the broad crested and Ogee. Variation of shape of spillway by using HEC-RAS has distinguishing variables. This variable is the Cd coefficient with magnitude of each form that is not equal. Cd value for each spillway form are shown in the following table.

TABLE II. Cd Values

Shape of Spillway	Nilai Cd
Ambang lebar *(broad crested)*	2,6 - 3,1
Ogee	3,2 - 4,1
Ambang tajam *(sharp crested)*	3,1 - 3,3

- Analysis of spillway dimension

In HEC-RAS 5.0.3, the debit formula is used as follows:

$$Q= Cd \times L \times H^{3/2}$$

The formula shown the larger spillway width, the greater of discharge that occurs. Variation in the dimension of the spillway width used are from 5 meters to 100 meters.

- Analysis of spillway location

The location of the spillway in term of the location of the spillway actually occurs. The first spillway is located in river sta 70.1. The second spillway is located in river sta 53.1.

B. Calibration

Calibration is carried out on the river sta 69-68 and river sta 3-2. River sta 69-68 is considered to be upstream which can be tied because there is 34th Surabaya Junior High School Bridge. River sta 3-2 is considered as downstream from the channel because there is Wiyung Bridge at the river sta.

The result of measurement of the average velocity and water depth of the channel are shown as follows.

TABLE III. Average of velocity and water depth

River sta	Average of velocity	Water depth
	m/sec	m
68	0,3	1
2	0,3	1,2

a) Boundary condition of calibration model.

- Upstream boundary condition

As the upstream boundary condition of this model is the discharge calculated as steady flow analysis. For river sta 69-68 with an average flow velocity of 0,3 m/second, channel dimension of 34 m^2, a discharge is 10,20 m^3/second is obtained. Meanwhile, for the river sta 3-2 with an average velocity of 0,3 m/second, channel dimension is 27.70 m^2, the discharge is 8.31 m^3/second.

- Downstream boundary condition

Downstream boundary condition data is the water depth every downstream of the river sta as shown in table III

b) Manning (n) value validation.

Manning value validation aims to obtain a value that is in accordance with the conditions of the depth of the water surface measured. The following is the result of trial and error to get a valid manning value.

TABLE IV. Manning validation for river sta 69-68

No	n	Q_{69} m^3/det	(H_{68ukur}) m	($H_{68model}$) m	Delta (m)
1	0.0350	10.2	1	0.96	0.04
2	**0.0375**	**10.2**	**1**	**1**	**0**
3	0.0400	10.2	1	1.04	0.04
4	0.0450	10.2	1	1.12	0.12
5	0.0500	10.2	1	1.18	0.18
6	0.0550	10.2	1	1.25	0.25
7	0.0600	10.2	1	1.32	0.32
8	0.0650	10.2	1	1.38	0.38
9	0.0700	10.2	1	1.45	0.45

TABLE IV. Manning validation for river sta 3-2

No	n	$Q_{2\text{-}3}$ m^3/det	(H_{ukur}) m	(H_{model}) m	Delta (m)
1	0.0350	8.31	1.2	1.09	0.11
2	0.0400	8.31	1.2	1.17	0.03
3	**0.0421**	**8.31**	**1.2**	**1.2**	**0**
4	0.0450	8.31	1.2	1.24	0.04
5	0.0500	8.31	1.2	1.31	0.11
6	0.0550	8.31	1.2	1.38	0.18
7	0.0600	8.31	1.2	1.45	0.25
8	0.0650	8.31	1.2	1.51	0.31
9	0.0700	8.31	1.2	1.57	0.37

For the river sta 69-68 it was found that the corresponding value of manning was 0.0375. Whereas for the river sta 3-2, the value of manning is 0.0421.

C. Model scenario

a) Boundary condition of model scenario

- Upstream boundary condition

The upstream boundary condition used in the form of flow hydrograph which has been calculated as design discharge in 10 years return period

- Downstream boundary condition

The downstream boundary condition is a normal depth by entering the channel slope, 0.00012 which is get from DEM data. The model scenario is simulated with unsteady flow analysis.

b) Hydraulic modeling for scenario model

In figure below, the geometry model that will be simulated is shown. Boezem is modeled as a storage area and surrounding settlement as a 2D area. Meanwhile, a spillway which is in right overbank river connected to the Boezem as lateral structure.

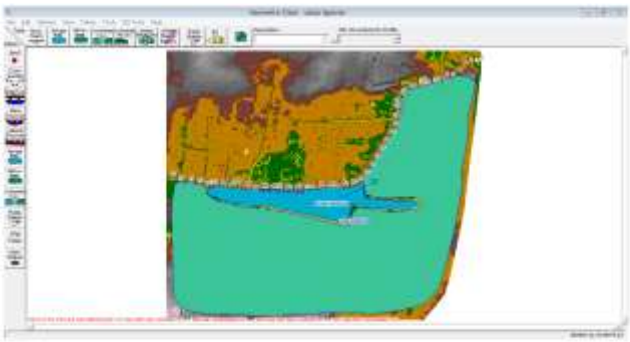

Fig. 6. Geometry of scenario model

D. Flowrate analysis in existing boezem condition

- Existing boezem condition

TABLE V. Flow Discharge over the overflow of existing boezem conditions

Scenario	Time (day)	Q (m^3/s)	TW stage (m)	Scenario	Time (day)	Q (m^3/s)	TW stage (m)
ERS1BL1	1	14.71	4.13	ERS1OL1	1	16.13	4.19
	2	16.83	4.25		2	18.11	4.32
	3	18.62	4.43		3	20.34	4.41
	4	21.28	4.63		4	23.41	4.62
	5	22.87	4.84		5	24.89	4.92
	6	24.65	5.22		6	26.11	5.32
	7	26.39	5.41		7	28.34	5.48
	8	27.12	5.58		8	31.45	5.63
	9	30.34	5.73		9	32.86	5.76
ERS1LB2	1	21.96	4.52	ERS1OL2	1	23.59	4.76
	2	24.27	4.65		2	25.11	4.95
	3	26.11	5.32		3	26.89	5.23
	4	27.89	5.47		4	28.15	5.43
	5	28.12	5.62		5	30.33	5.72
	6	29.45	5.75		6	32.14	5.78
	7	-	-		7	-	-
	8	-	-		8	-	-
	9	-	-		9	-	-
ERS1LB3	1	27.67	5.41	ERS1OL3	1	29.87	5.65
	2	28.34	5.67		2	31.38	5.71
	3	29.61	5.75		3	32.10	5.75
	4	-	-		4	-	-
	5	-	-		5	-	-
	6	-	-		6	-	-
	7	-	-		7	-	-
	8	-	-		8	-	-
	9	-	-		9	-	-

In table V above, the results for flowrate above the spillway for spillway are displayed, which is located at the river sta 70.1. The relationship of discharge with the variation of the dimensions of the overflow width is the greater the dimension of the overflow, the greater the flow rate above the overflow. This is in accordance with the hydraulics equation calculated above in the equation (4-1) above. That Q = Cd x L x $H^{3/2}$, along with the increase in the value of L, the greater the debit Q produced. For the variety of types of spillway used, there is an Ogee type produce a discharge that is greater than the width Broad Crested type. This is in accordance with the size of the Cd coefficient used for each type of overflow lighthouse, where the Cd coefficient for the Ogee type is greater than the width Broad Crested type.

To determine how effective the enlargement width is, the Tail Water (TW) stage is used as a limitation. The TW stage in question is the maximum limit of water level in the boezem that can be accommodated according to the curve of boezem capacity which is at +5.8 meters. The ERS1BL1 and ERS1OL1 code scenarios can meet the maximum boezem capacity after 9 simulation days. The ERS1BL1 code scenario occurs TW stage at +5.73 meters with a discharge of 30.34 m^3/sec.

Scenario with dimensions of L2 overflow width (width of 20 meters), ie ERS1BL2 code scenario and ERS1OL2 scenario code can meet maximum boezem capacity after 6 simulation days. For the scenario code ERS1BL2 occurs TW stage at + 5.75 meters with the resulting discharge 29.45 m^3/sec. Whereas for the ERS1OL2 scenario code gets the maximum boezem capacity at TW stage + 5.78 meters with a discharge of 32.14 m^3/sec.

Furthermore, for variations of the L3 (30 meter) overflow width, the ERS1BL3 code scenario and ERS1OL3 code scenario can achieve maximum boezem capacity after 3 days of simulation time. The ERS1BL3 code scenario reached TW stage + 5.75 with the resulting discharge 29.61 m3 / sec and the ERS1OL3 scenario code reached TW stage 5.75 with the resulting discharge 32.10 m^3/sec. From all the results that have been obtained, it can be concluded that every large dimension of the overflow width increases, it will also increase the amount of discharge. However, the width of the spill that can be used can be adjusted to the large TW stage obtained so that the spillway width can function effectively.

- Dredged boezem condition

TABLE VI. Flow Discharge over the overflow of dredged boezem conditions

Scenario	Time (day)	Q (m^3/s)	TW stage (m)	Scenario	Time (day)	Q (m^3/s)	TW stage (m)
KRS1BL1	1	14.74	3.07	KRS1OL1	1	18.13	3.15
	2	16.86	3.16		2	20.25	3.24
	3	18.65	3.25		3	22.04	3.32
	4	21.31	3.32		4	24.70	3.40
	5	22.90	3.39		5	26.29	3.47
	6	24.68	3.49		6	28.07	3.56
	7	26.42	3.58		7	29.81	3.66
	8	27.15	3.67		8	30.54	3.75
	9	30.37	3.76		9	33.76	3.84
	10	30.49	4.02		10	33.88	4.10
	11	30.70	4.12		11	34.09	4.19
	12	31.24	4.20		12	34.63	4.27
	13	31.79	4.27		13	35.17	4.35
	14	32.71	5.26		14	36.09	5.34
	15	33.47	5.38		15	36.85	5.46
	16	33.53	5.60		16	36.92	5.68
KRS1BL2	1	22.57	3.43	KRS1OL2	1	25.96	3.51
	2	24.69	3.53		2	28.08	3.61
	3	26.48	3.63		3	29.87	3.70
	4	29.14	3.72		4	32.53	3.79
	5	30.73	3.81		5	34.12	3.88
	6	32.51	4.07		6	35.90	4.14
	7	34.25	4.16		7	37.64	4.24
	8	34.98	4.24		8	38.37	4.32
	9	38.20	4.32		9	41.59	4.40
	10	38.32	5.31		10	41.71	5.38
	11	38.53	5.43		11	41.92	5.50
	12	39.07	5.65		12	42.46	5.73
	13				13		
	14				14		
	15				15		
	16				16		
KRS1BL3	1	26.57	4.13	KRS1OL3	1	29.96	4.21
	2	31.57	4.23		2	34.96	4.31
	3	32.47	5.01		3	35.86	5.09
	4	33.42	5.61		4	36.81	5.69
	5	35.42	5.66		5	38.81	5.74
	6	39.42	5.69		6	42.81	5.77
	7	40.40	5.71		7	43.79	5.79
	8				8		
	9				9		
	10				10		
	11				11		
	12				12		
	13				13		
	14				14		
	15				15		
	16				16		

The simulation results using dredged boezem conditions are that the amount of discharge that occurs is approximately the same as the amount of discharge when the existing boezem condition. Changes occur in the large TW stage for each simulation performed. The scenario with a 10 meters overflow width, for the KRS1BL1 code scenario and the KRS1OL1 code scenario reaches the maximum TW stage at 16 days simulation time. As for the 20 meters spill width, the KRS1BL2 code scenario and the KRS1OL2 code scenario can reach the maximum TW stage with a simulation time of 12 days. Simulation of 30 meters spill width, KRS1BL3 code scenario and KRS1OL3 code scenario can reach the maximum TW stage after 7 days of simulation.

E. Analyisis of Water Level Reduction in Kedurus Primary Channel

TABLE VII. Decrease in average water level in the channels of each scenario

No	Scenario	Time (day)	Water level decrease (cm)
1	ERS1BL1	9	71
2	ERS1BL2	6	59
3	ERS1BL3	3	40
4	ERS1OL1	9	68
5	ERS1OL2	6	41
6	ERS1OL3	3	32
7	KRS1BL1	16	51
8	KRS1BL2	12	43
9	KRS1BL3	7	22
10	KRS1OL1	16	48
11	KRS1OL2	12	34
12	KRS1OL3	7	20

The simulation results by using the HEC-RAS 5.0.3 auxiliary program show that each water level decreases with increasing spillway width. However, this decline can reach water level conditions below the river bank elevation (no overflow), only when the maximum simulation time is complete with a decrease in the average water level.

F. Analysis of Inundaton in Settlements

This analysis was carried out by placing a sample of inundation points in the settlement area that had been simulated as 2D areas. The point sample is shown by using the map contained in the RAS Mapper as follows.

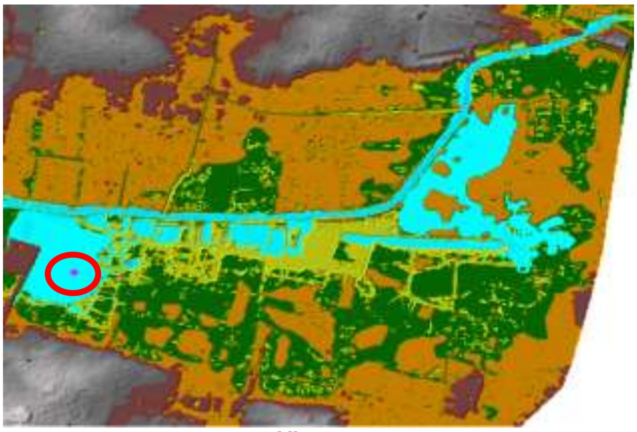

Fig. 7. Puddle monitoring point

Sampling points of inundation are placed in the position of the maximum inundation depth as shown in Figure 7 above. The following is a recap of the inundation depth and the length of inundation that occurred. For monitoring of inundation it is carried out for 24 hours. In this condition the inundation depth is shown as in the following table.

TABLE IX. The maximum inundation depth and duration of the simulation pool are 24 hours

No	Scenario	Max Depth (m)	Duration of Inundation (jam)
1	ERS1BL1	1.1	6
2	ERS1BL2	0.89	5
3	ERS1BL3	0.67	3
4	ERS1OL1	0.93	6
5	ERS1OL2	0.76	4
6	ERS1OL3	0.63	2
7	KRS1BL1	0.58	6
8	KRS1BL2	0.43	3
9	KRS1BL3	0.23	2
10	KRS1OL1	0.51	5
11	KRS1OL2	0.32	4
12	KRS1OL3	0.22	1

The results in table IX show that the inundation depth decreases in each modeled scenario. The simulation time to monitor inundation depth is not the same as when monitoring water level drops on the Kedurus Primary Channel. This is due to monitoring the decrease in water level in the channel associated with the amount of discharge entering the boezem.

G. Effective Analysis of Boezem Storage

Shown in table 4.28 that the modeled scenario can accommodate water maximally. For the selection of the most effective type of scenario is to compare the results of each analysis that has been done. In this modeling, it can be seen that the spill width only affects the flow rate above the spill that enters the reservoir so that a decrease in the water level on the Primary Channel occurs. The water level on the Primary Channel drops, causing the inundation depth in the residential area to also drop. Meanwhile the amount of boezem storage that occurs, can only depend on the maximum volume capacity of the boezem from the curvature of capacity that is affected by the simulation time. The amount of overflow flow that occurs between existing and dredged boezem conditions is the same. However, boezem with dredged conditions has a large capacity so that it can be used to hold more water in a long time.

TABLE X. Percentage of boezem volume that can be used

No	Scenario	Capacity Curve Volume (m3)	Maximum Simulation Volume (m3)	Which can be used
1	ERS1BL1	481.88	471.13	98%
2	ERS1BL2	481.88	468.44	97%
3	ERS1BL3	481.88	473.21	98%
4	ERS1OL1	481.88	480.54	100%
5	ERS1OL2	481.88	470.22	98%
6	ERS1OL3	481.88	477.56	99%
7	KRS1BL1	972.26	971.78	100%
8	KRS1BL2	972.26	952.57	98%
9	KRS1BL3	972.26	961.57	99%
10	KRS1OL1	972.26	970.89	100%
11	KRS1OL2	972.26	971.13	100%
12	KRS1OL3	972.26	971.12	100%

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

IV. Conclusions and Recommendations

A. Conclusions

In this study it can be concluded that as follows:

1. Scenario variations are carried out using dimensions of overflow widths of 10 meters, 20 meters and 30 meters. The shape of the spillway used is the wide threshold type and Ogee. The DEM map used is when the existing boezem condition with a volume of 488,810 m3 and boezem conditions dredged with a volume of 979,342 m3.
2. Scenarios are modeled by using storage area analysis in the boezem and for inundation areas analyzed using 2D area.
3. The relationship of the flow velocity distribution for each River Sta location with respect to each variation in the spill dimensions and spillway dimensions is as follows.
   - Existing Boezem conditions with a variety of overflow formations, the large flow velocity distribution both upstream and downstream of the overflow increases with increasing spill length dimensions.
   - The condition of the Boezem when dredged with a variety of overflow formations, the large distribution of flow velocities both upstream and downstream of the overflow increases with increasing dimensions of the length of the spill.
   - By using a width dimension of 30 meters, it can reach the maximum TW stage.
4. The size of the water level in the Kedurus Primary Channel is simulated using the boezem storage capacity fulfillment time. For the scenario. The biggest scenario to reduce the water level on the channel is ERS1BL1 of 71 cm.
5. The large decrease in inundation depth in settlements calculated in the 24-hour simulation produces inundation length of at least 1 hour with an average depth of 22 cm inundation using the KRS1OL3 scenario.
6. The carrying capacity that occurs depends on the change in simulation time. When the boezem condition is dredged, it takes longer to load the pump than the existing boezem condition. But the volume of boezem when dredged is greater than the existing boezem volume. For existing boezem conditions and boezem conditions dredged using 30 meters of spill width and type of Ogee lighthouse, it requires the least amount of time to reach a maximum storage capacity of 3 days.

B. Suggestion

This suggestion is conveyed based on the author's experience in working on modeling. It is expected that when reading wants to do a similar model to make the following suggestions:

1. When using the Digital Elevation Model (DEM) map, it must be matched with field conditions. At least matching is done against cross section of field conditions. This is because the DEM maps obtained are usually less accurate on river cliff conditions.
2. In working on modeling using open source software, software should be used with the latest version. This is done to avoid lack of models that have been made.
3. Before creating a project on the HEC-RAS program, it is better to create folders first separately to facilitate the storage of each simulation with different project scenarios.

References

[1] Anggrahini (1997), *Hidrolika Saluran Terbuka*, CV. Citra Media, Surabaya
[2] Chow, Ven Te (1995), *Open-Channel Hydraulics*, McGraw-Hill Book Company Inc, United States of America
[3] US Army Corps of Engineer (2016), *Hydraulic Reference Manual Version 5.0.*, California
[4] US Army Corps of Engineer (2016), *User's Manual*, California
[5] Istiarto (2014), *Model Hidrodinamika*, Universitas Gadjah mada, Yogyakarta
[6] Istiarto (2014), *Simulasi Aliran 1-Dimensi Dengan Bantuan Paket Program Hidrodinamika HEC-RAS*, Universitas Gadjah mada, Yogyakarta
[7] Metha, dkk (2008), *Studi Evaluasi Drainase Kota Ungaran Bagian Barat dengan Program EPA SWMM 5.0*, Universitas Katolik Soegijapranata, Semarang
[8] Restu, dkk (2012), *Analisis Pengaruh Kemiringan Dasar Saluran Terhadap Distribusi Kecepatan dan Debit Aliran Pada Variasi Ambang Lebar*, Universitas Sultan Ageng Tirtayasa, Jawa Barat
[9] Soemarto (1999), *Hidrologi Teknik*, PT. Pradnya Paramita, Jakarta
[10] Sosrodarsono, Suyono dan Kensaku Takeda (2002), *Bendungan Type Urugan*, PT. Pradnya Paramita, Jakarta

Anna Amalia Misdanik and Umboro Lasminto, "Numerical Modeling of Variation in Spillway Dimensions and Variation in the Shape of Spillway for the Effectiveness of Boezem," *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 3, pp. 230-235, 2019.