Hydrodynamics Analysis of Sewerline Obstruction at Segget River

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ABSTRACT: In the end of July 2015, a flash flood occurred in Johor Bahru where the affected area are along Jalan Wong Ah Fook and Jalan Sultan Ibrahim located near to Shopping Complex City Square and JBCC Mall. Along the lower Segget river there is one crossing sewerline network. In future,what will be the impact on the water surface profile and sedimentation due to the sewerline obstructing the river bed?. Will there be any damage on the structure of sewerline? In this study, a simulation of the hydrodynamics and sediment transport of sewerline obstruction at Segget river are presented using Flow 3D. A sewerline structure with the dimension of 6 x 1 x1 m^3 was constructed in a box culvert drain. The water flowing in the sewerline is a combined flow from Wadi Hana and Wadi Hassan subcatchment. Rational Method is used to calculate total peak discharge for combined flow from both subcatchment with different Annual Recurrence Interval (ARI) which is 5,10 and 100 years. The total peak discharge is the main input of the boundary condition at Xmin (inlet) to identify water surface profile and behaviour of bed sediment in four minutes simulation. Results shows the hydraulic parameters such as the flow depth, velocity, pressure, turbulent energy and sediment transport through box culvert drain. Conclusions can be made that as the total peak discharge increases, so does the flow depth, velocity, pressure and turbulent energy. However, sedimentation are seen to accur more for lower ARI. Furthermore, the sediment accumulation will be occurred behind a sewerline structure while sewerline scour is not occur in short simulation. . Four minutes simulation is not enough to analysis the back flow at upstream and downstream of the sewerline obstruction in the river. However, this study may be improved with a longger simulation time for the hydrodynamics analysis and sediment transport with a higher processing computer.

Keywords: Flow 3D software, Annual Recurrence Interval (ARI), Peak Discharge, Sewerline structure, Boundary Condition, Mesh, Box culvert

INTRODUCTION

Today, in the midst of the most recent era of globalisation most country in the world faced the same impact on their urban area which are urbanisation and climate change. Urbanisation refers to the increasing number of people from rural area shift to live in urban area. Thus, the relationship between the urban development increase throughout the year that induced by population growth in urban area so that no wonder the urban development increases flood risk in cities due to local changes in hydrological and hydrometeorological conditions [1] .Furthermore, the increasing concentration population in cities also can cause climate change. The impact of climate change include; sea-level rise and tidal effect, increase river runoff and enhancement extreme rainfall due to urban growth driven urban heat island [1]

In Johor Bahru, Malaysia, the population is expected to increase to three million by 2025 [2]. Johor Bahru is located at the southern west of Malaysia, commonly Malaysia's climate known as the tropical with a high rainfall, hot and humid throughout of year. The average annual rainfall received by the peninsula is 2,500 mm while Sabah and Sarawak are 3,500 mm [3]. Increasing of urban runoff in cities may be due to increasing of extreme rainfall intensities and urban growth. Flash flood will occur in a certain period as capacity of river may exceed particularly in urban area. This include Segget River in Johor Bahru.

Problem Statement

Since Johor considered as a developing state, but it also faced flooding problem. The factors that contribute to flooding are identified from weather condition, geological aspect, and poor management of drainage system. It has been known for over the years, news has been reported multiple times of flooding record especially when it comes with monsoon season and due to human activities.

Segget River covers about 3.8km and located in the middle of Johor Bahru city. Flooding in area of Segget River is a frequently occurs. It can be caused by flash flood, monsoon season and also human activities. Runoff from Wadi Hassan (North West) and Wadi Hana (North East) also through Segget River. Moreover, there has been an obstruction in river bed of Segget river which is sewer line network. In the end of July 2015, a flash flood is occured in Johor Bahru where the affected area are along Jalan Wong Ah Fook and Jalan Sultan Ibrahim located near Shopping Complex City Square and JBCC Mall is caused by heavy rainfall and weir construction work. It is obstructing the waterway and causing flooding in Segget River [2]&[6]. The flood depth around 0.3 m and no evacuate residents is reported [6]. Therefore, according to Iskandar Regional Development Authority (IRDA), after Segget river restoration is completed in 2017 no flash flood will be occurred [7]. This will put a remark on how progress has been achieved along the time to manage flash flood problems in the city and what ought to be done in future. However, along the lower Segget river there is one crossing sewerline network as shown in figure 1. So, Is there give any impact on water surface profile due to sewerline obstruction in river bed and give damage on sewerline obstruction? .

Objectives

Since, the crossing sewerline as an obstruction in Segget River. It is may give one impact on flash flood in future. This paper will predict and simulate the flow behaviour at upstream and downstream through a sewerline obstruction in Segget river using Flow 3D software. The objectives of this study are:

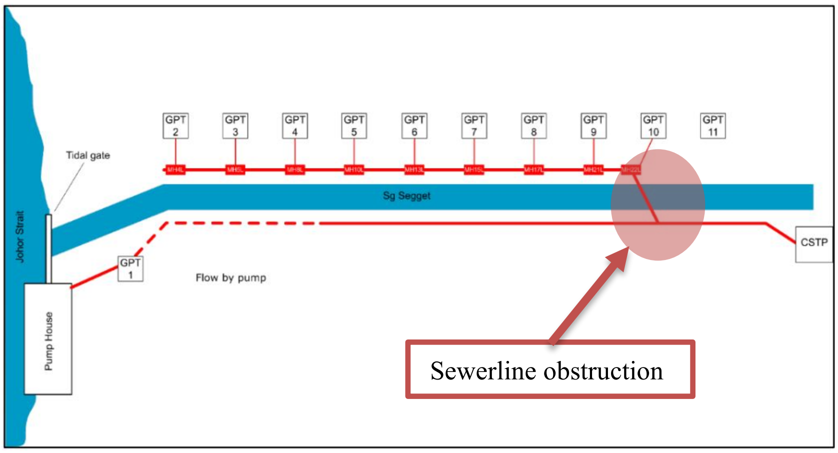
1. To identify the flow hydrodynamics at upstream and downstream through a sewerline obstruction in Segget River
2. To identify the impact of sewerline obstruction in Segget River due to sediment transport

Scope of Study

The outlet of Segget river is flowing into Straits of Johor areas are experienced low and high tide. In this study, a simulation of flow hydrodynamics of a sewerline obstruction in Segget river is for a low tide. hence, the tide is lower than river level, so the tidal gate will be opened. Other than that, a water flow through a sewerline is combined flow from Wadi Hana and Wadi Hassan subcatchment.The calculation of total peak discharge for combined flow from Wadi Hana and Wadi Hassan subcatchment is using Rational Method. Lastly, since the estimation of peak discharge is calculated and experienced for low tide only that will become input data in a simulation model using Flow 3D. Since, the steady flow through a sewerline obstruction in Segget river will get between three to four minutes and more. The assumption of simulation model is running for four minutes (steady flow) only.

LITERATURE REVIEW

Study Area. A crossing sewerline at Segget river will be conducted as shown in figure 1(a). A sewerline is crossing through concerete Box culvert has dimension 2.5x6 m^2 and a sewerline simirlarly with rectangle structure has dimension 6x1x1 m^3. In figure 1(b) a structure is also similar with broad-crested weir. In further study, flow behaviour of broad crested weir can be referenced.



(a)

(b)

Figure 1: (a) schematic of drainage and sewerline for lower Segget [8]. (b) The structure of sewerline [8]

Sediment Deposition. Sediment deposition refers to move the inorganic and organic particle in the river till sediment stopped by obstruction and slowly settle on the river bed. All rivers have their own sediment particle either large or small size. Usualy, river flows from upstream to downstream are commonly sediment will accumulate against upstream side of obstruction is more than downstream side [10]

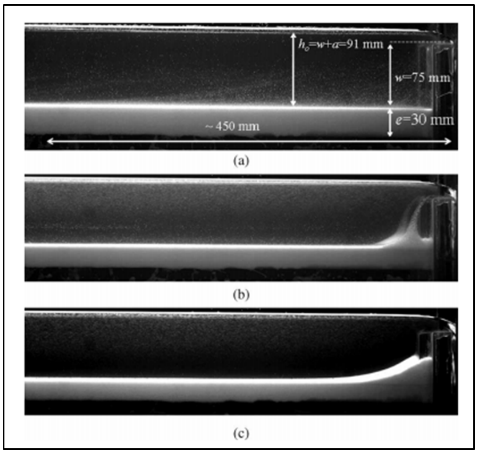


Figure 2: the behaviour of bed particle due to flow rate and height of weir [10]

Model Equations. In this study, the commercial CFD software, Flow 3D which applies the fluid equations of motion to solve the non-linear, transient, second-order differential equations to describe the motion of the fluid is used. The governing equations involved include the continuity Equations (1) and (2) and Reynolds-averaged Navier-Stokes Equations [4].

$$\frac{\partial \rho}{\partial t} + \Delta.(\rho v) = 0 \tag{1}$$

Where,

$$\Delta.(\rho v) = \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z} \tag{2}$$

where ρ is the density, t is the time and u, v and w are the velocity of flow in x, y and z directions.

$$\rho \frac{Dv}{Dt} = \rho g - \Delta P + \mu \Delta^2 .v \tag{3}$$

Navier-Stokes equation can be expended into three equations to describe the flow motion in three coordinate system as in Equations

$$\rho \frac{Du}{Dt} = \rho g_x - \frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} \right) + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \tag{4}$$

$$\rho \frac{Dv}{Dt} = \rho g_y - \frac{\partial p}{\partial y} + \mu \left(\frac{\partial^2 v}{\partial x^2} \right) + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \tag{5}$$

$$\rho \frac{Dw}{Dt} = \rho g_z - \frac{\partial p}{\partial z} + \mu \left(\frac{\partial^2 w}{\partial x^2} \right) + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \tag{6}$$

In Flow-3D each cell in the fluid domain has water volume fraction (F) ranging between 0 and 1. Where 1 represents cells that are fully occupied with water, while 0 represents cells that fully occupied with air. Values between 1 and 0 represent free surface between air and water.. Flow-3D defines the free surface elevation by using the volume of fluid (VOF) function in Equation

$$\frac{\partial F}{\partial t} + \frac{1}{V_F} \left[\frac{\partial}{\partial x}(FA_x u) + R \frac{\partial}{\partial y}(FA_y v) + \frac{\partial}{\partial z}(FA_z w) + \varepsilon \frac{FA_x u}{x} \right] = F_{DIF} + F_{SOR}$$
…. .(7)

where VF is Volume of fluid fraction, F is the volume flow function, F_{SOR} is the source function, Ax; Ay; Az represent the fractional areas, u, v and w are velocity components in x, y and z directions.

METHODOLOGY

This study consisted of two key activities; the identification of peak discharge by using Rational Method and the simulation set-up in Flow 3D software,

The identification of Peak Discharge using The Rational Method

There are seven steps for estimating a peak discharge from a subcatchment Wadi Hana and Wadi Hassan for a particular ARI using the Rational Method as outlined in figure 3:

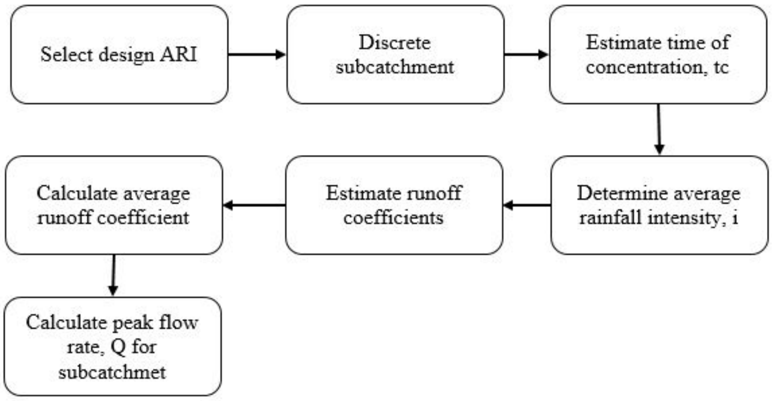


Figure 3: Procedure for Estimating Peak Flow Using the Rational Method [9]

The rational method is to predict the peak discharge according to the formula:
Qpeak $=\frac{CiA}{360}$. (m^3/s) C= runoff coefficient, C, I= Rainfall intensity, i (mm/hour), A = Subcatchment Area (ha) (Eq. 1)

The simulation set-up in Flow 3D software

There are several steps in the development of a simulation modelling in Flow 3D which are simulation manager, global, physics, fluids, geometry, meshing, boundary conditions, initial conditions and finally output. For simulation manager, project model is to create a new workspace to organise the simulation. Moving to the model setup tab to define simulation finish time. Then, for basic free surface simulations the only required physics models are gravity and turbulence but for sediment transport adds on sediment scour in physics models. Next, properties for water must be define on fluids dock widget, and can be loaded from the materials database. From the material database choose water at 20°C for material properties. Furthermore, geometry for a sewerline obstruction is created by 3rd party CAD software, need to add it as a new component during the STL import process. For channel bed will be defined using FLOW-3D primitive subcomponent but different setting for sediment transport, for channel bed will be new component to identify as packed sediment. The structure has lateral symmetry, can define the computational mesh as a vertical slice of the obstruction sewerline that is a single cell thick. This assumption allows for a reduced cell count and faster run times. In addition, boundary condition to define water surface profile and sediment transport using variation of volume flow rate as the inlet (Xmin), the outlet (Xmax) and maximum height of modelling (Zmax) using pressure boundaries. Table 1 shows that the input data in boundary condition and table 2 shows characteristics of sediment is required to fill in physics model, sediment scour.

Table 1: Varitation of peak discharge

Catchment	Area (km^2)	5 year (m^3/s)	50 year (m^3/s)	100 year (m^3/s)
North East	0.8	12	17	20
NorthWest	1.0	18	25	30
Total Peak Discharge		30	42	50

Table 2: Characterisitics of sediments

Name	Diameter	Density	Critical Shields Number	Entrainment Coefficient	Bed Load Coefficient	Angle of Repose (Degrees)
Coarse Sand	0.001	2650	0.05	0.018	8	32
Gravel	0.0069	2650	0.05	0.018	8	32
Coarse Gravel	0.0105	2650	0.05	0.018	8	32

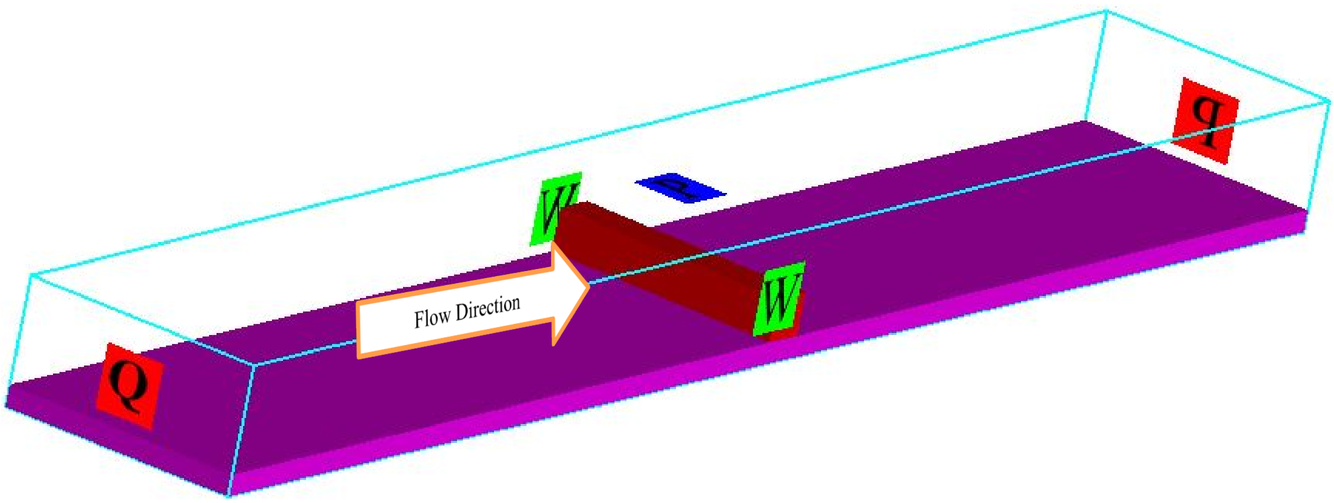


Figure 4: Boundary Condition Setting

Table 3: Implemented boundary conditions in the simulation model

Boundary	X-Min	X-Max	Z-Max	Z-Min	Y-Min&Max
Boundary Condition	Volume flow rate	Pressure	Pressure	Symmetry	Wall

Moreover, Initial conditions is define to add fluid at the approximate locations where flow is expected at steady state. A combination of fluid region and global conditions is used to define different water elevations upstream and downstream of a sewerline obstruction. Point probe is create to measure hydraulic parameters such as the turbulent energy, froude number, velocity, hydraulic head, pressure and water depths through a sewerline obstruction. Lastly, the output is to define the data to be written to the results file and then run simulation on the local machine.

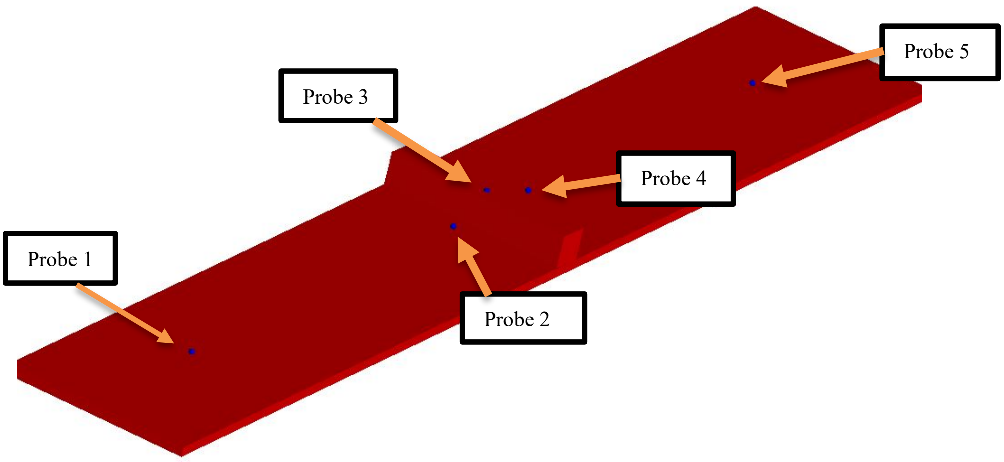


Figure 5: The setting of point probe

RESULTS AND DISCUSSION

The results on the simulation set-up in Flow 3D software to analyse hydrodynamics of a sewerline obstruction are discussed herein. In this case study, the flow properties of a sewerline obstruction in Segget River with the dimension 6x1x1 m^3 is modelled numerically using flow 3D and bedding plane is 20x0.3x6 m^3. Results showed that the hydraulic parameters such as the water depths, velocity, pressure, turbulent energy sediment concentration through a sewerline obstruction were able to simulated.The main purpose in this case study is to identify water surface profile of a sewerline at upstream and downstream of segget river, and sediment concentration for peak discharge of ARI 5, 10 and 100 years.

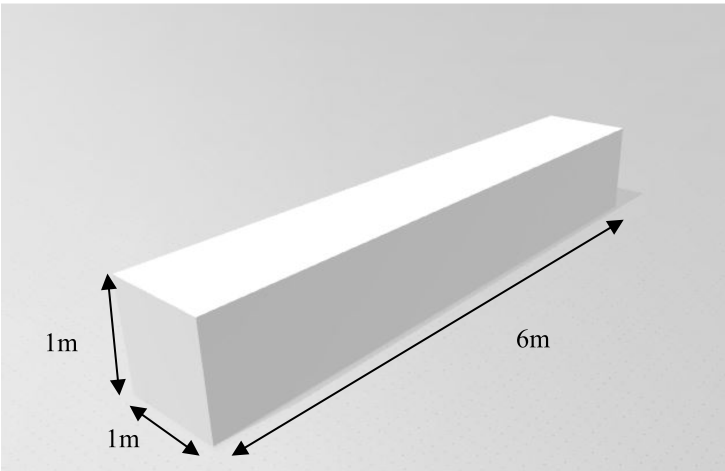


Figure 6: The geometry of a sewerline obstruction

Table 4:The dimension of box culvert [8]

Chainage	Lowest Invert Level	Ground Level	Depth	Width	Type
1125	0.925	3.409	2.484	6	Box Culvert

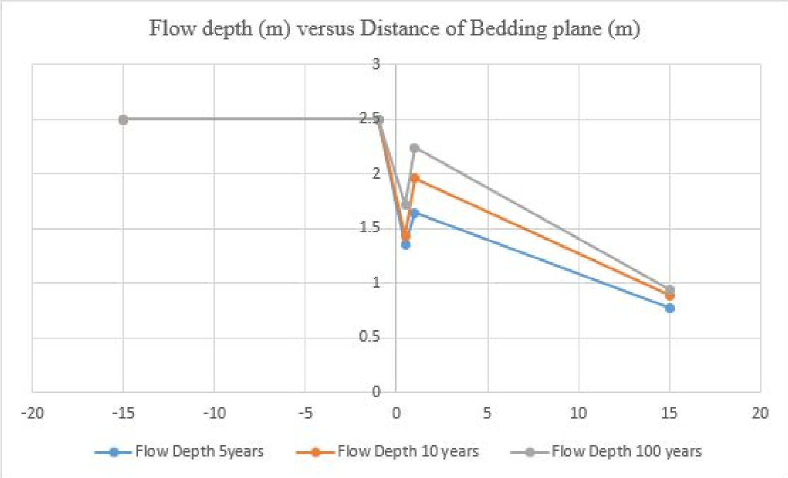


Figure 7: Water depth variation under three cases of peak discharge variations

Flow Characteristics

In this study, a sewerline obstruction at Segget River are analysed using Flow 3D software results. Figure 7 shows the water depth variation from upstream to downstream under three (3) cases of peak discharge variation (30m^3/s, 42 m^3/s and 50 m^3/s). From the graphs, it can be observed that the water depth before a sewerline obstruction (upstream) are similar for all case. This is because the shape of drainage is box culvert has dimension 2.5x6 m^2 while water depth after a sewerline obstruction (downstream) increase with an increase in peak discharge.The highest discharge at a depth of about 2.5 m at the upstream and about 0.94 m at the downstream. The increase in the water depth is a result of the presence of a sewerline obstruction which changes the flow pattern and hydraulic characteristics.

Velocity

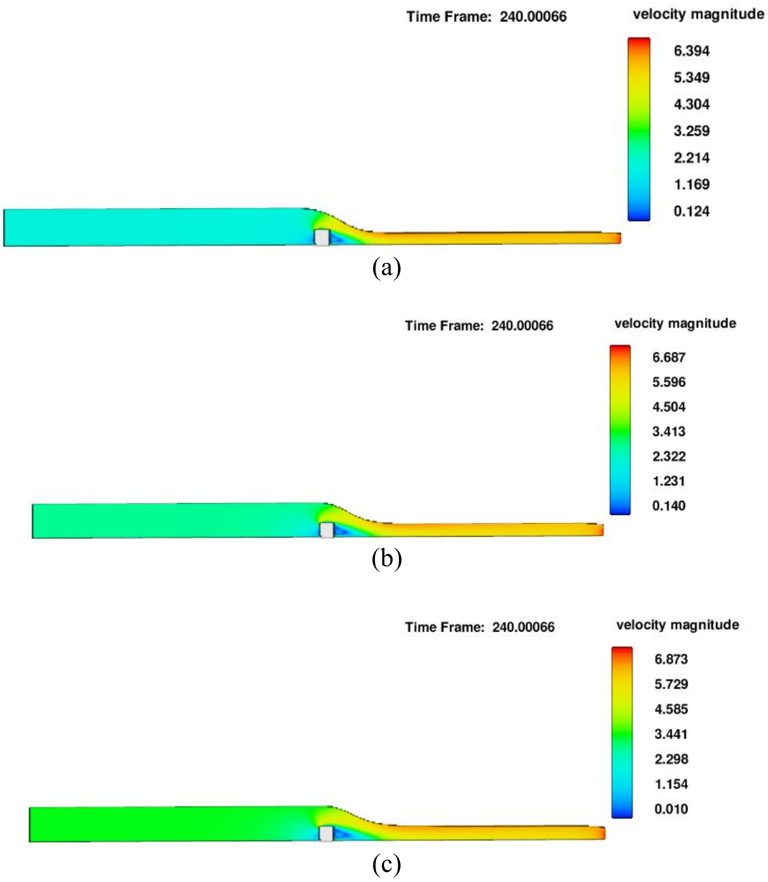
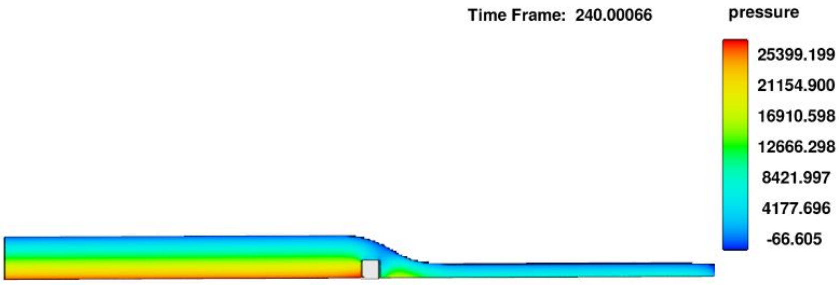
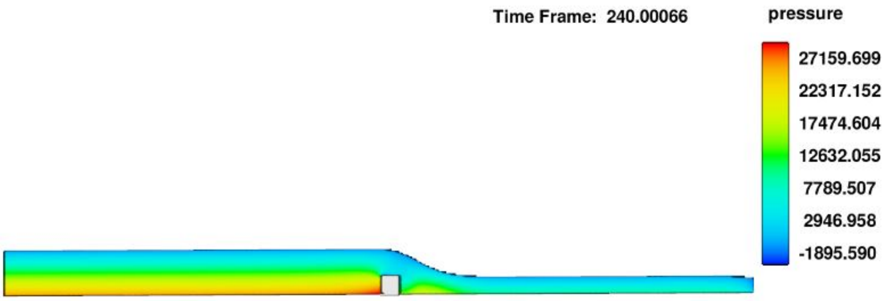


Figure 8:Flow velocity variation contour for future development (a) 5 years, (b) 10 years and (c) 100 years

Pressure



(a)



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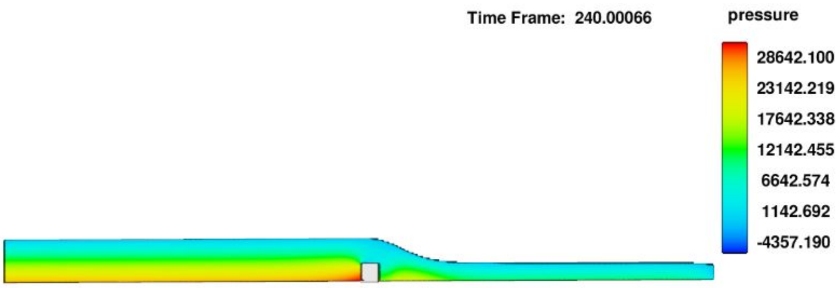


(c)

Figure 9: Pressure variation contour for future development (a) 5 years, (b) 10 years and (c) 100 years

Turbulent Energy

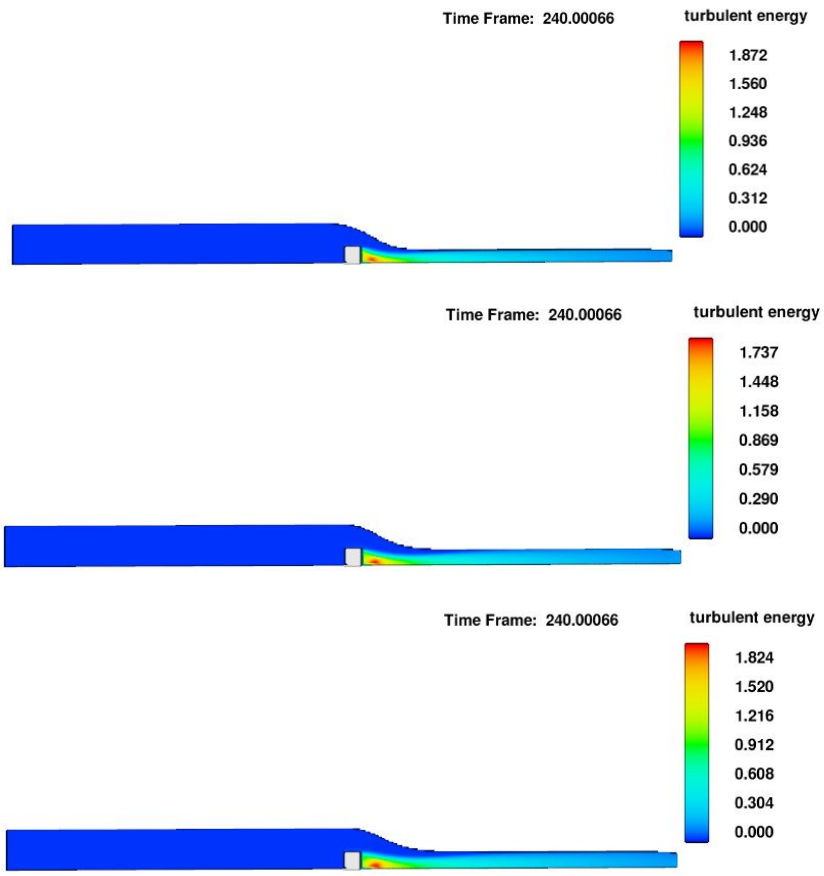
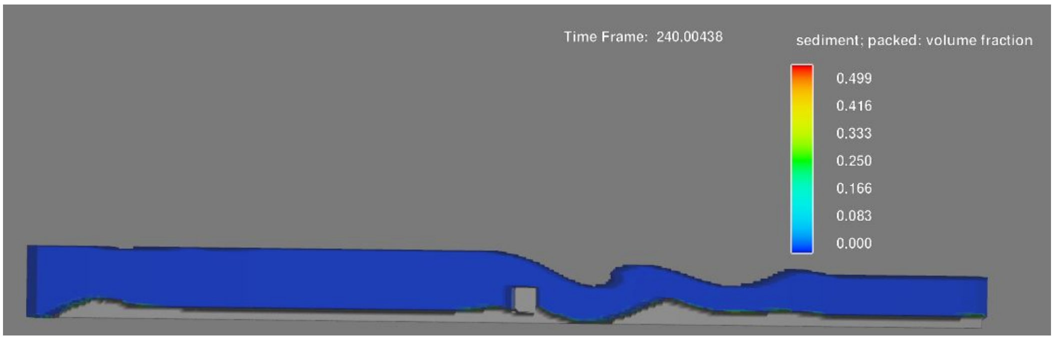
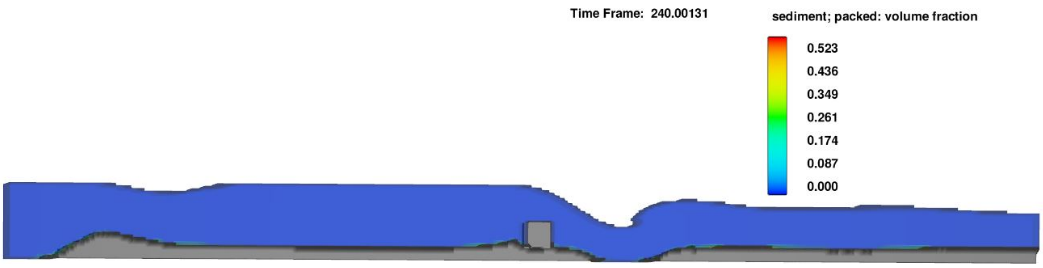


Figure 10: Turbulent Energy variation contour for future development (a) 5 years, (b) 10 years and (c) 100 years

Sediment Transport



(a)



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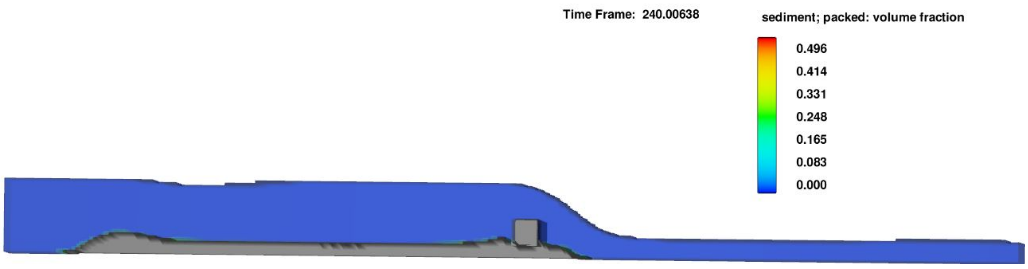

(c)

Figure 11: Sediment Transport variation contour for future development (a) 5 years. (b) 10 years and (c) 100 years

Figure 8 show the variation of the flow velocity from upstream to downstream. It can be clearly observed that the flow has higher velocity at downstream that at the upstream this is because the effect of sewerline obstruction generated more pressure at the upstream side and less at the downstream side as shown in figure 8 and figure 9. In addition, Figure 10 shows the turbulent energy variation is quiet steady turbulent flow at upstream side while there has variation contour at downstream side. However, turbulent energy is low at surface water and high closer to the base of river. In figure 11 the height of sediment accumulate at behind a sewerline are increasing due to peak discharge increases. However, the sediment accumulates more in front of the obstruction for lower ARI Q peak. In long term, the height of sediment accumulate may be equalled with height of sewerline and will effect the drainage capacity.

CONCLUSION

In this paper, the study modelled the hydrodynamics analysis of sewerline obstruction at Segget River using Flow 3D software.Findings conforming to the objectives of this study can be summarised as below:

1. The hydrodynamics of the flow was simulated as shown in figure 7,8,9, and 10. The relationship between the increasing of peak discharge with the flow depth, velocity, pressure and turbulent energy shows that as the peak discharge increases so does the velocity, pressure and turbulent energy.
2. Since the dimension of box culvert is 2.5 x 6 m^2 meshing is constructed as to real geometry,the flow depth at upstream side of the obstruction was in full capacity. Overflow at upstream side will not occur unless there are an opening. However, it would be beneficial to assess on the pressure that may be build in the box culvert by adopting longer simulation time. Back flow may be observed with longer simulation time.
3. Sediment scour under a sewerline obstruction may not occur for peak discharge of ARI 5,10 and 100 years but the sediment accumulation may occurr behind and infront of the sewerline obstruction. It may give some additional shear force on sewerline structure. Thus, erosion and cracking on the structure may happen time by time.

This study concludes that, a crossing sewerline in Segget river can be one of obstruction in future. This is because from simulation, it can be clearly observed the flow hydrodynamics such as velocity, pressure, turbulent energy and sediment transport will increase for the peak dishcarge of ARI 100 years. The bed sediment behaviour will accumulate behind a sewerline structure can give some additional shear force as showed by the turbulent energy. In long term, the structure may erode and crack due to additional shear force. Moreover, Flow 3D can be recommended as a useful tool to predict the behaviour of river in discharge measurements, upstream and downstream flow stabilisation and lastly longer simulation time is recommended for future studies.

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