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Modification of natural waterway shape as a river trash interceptor–an approach model for Citarum River recovery

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Abstract. The Citarum River is the most polluted river in Indonesia. The river irrigates three cascade reservoir such as Saguling, Cirata and Jatiluhur, which serve for hydroelectric power plant, drinking water, agricultural irrigation and fishery. Solid municipal waste and agricultural debris that is dumped into the river cause destruction of river habitats, flooding and shallowing especially in cascade reservoirs. This study aims to develop an idea of river recovery from waste, by using namely river trash interceptor (RTI) located at the Citarum river tributaries due to the economic consideration and efficiency. By using CFD (Computational Fluid Dynamics) and Particle Tracing module, the form of the interceptor is simulated based on the mostly general form of the Citarum River waterway; straight line shape, bend shape and U-type shape. The parameters used are river depth, river width, water discharge, particle size and density. These results of this study could be used as a reference for decision makers and developers on further development of the RTI in the near future.

1. Introduction

Citarum river located in West Java province in Indonesia with the length of 323 km is the 'main stem' river or the primary downstream segment of a river [1]. Using the classic stream order, the Citarum river is the 1st order river to its mouth in the Java sea. The Citarum river have 53 of 2nd order tributaries with total length 710 km, 104 of 3rd order tributaries with total length 666 km, 61 of 4th order tributaries with total length 290 km and 39 of 5th order tributaries with total length 224 km [2].

The river is heavily polluted by human activity. The river passes through 13 administrative areas of district and cities [3] with an average density of 400-12,000 people / km2 [4], nearly 25 million people dependent on the Citarum River [5]. Disposing waste into the river is a habit that is entrenched in most people of West Java. In the past when the population was still small, there was no large industry and no massive use of plastic, this condition could still be tolerated by the river, due to the ability of the river could still decompose the organic waste. Nowadays, especially plastic waste has filled the river, causing blockages, bad smells and deaths in the river habitat. Another impact is siltation and sedimentation the cascade reservoir (Saguling, Cirata and Jatiluhur) that caused the high in maintenance of hydroelectric power plant installations.

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This study aims to develop a model to collect river waste, by trapping and lifting garbage from river stream. The goal of this study is to design a river trash interceptor (RTI) that's:

- Capture mostly wastes by using its stream turbulence.
- Located the 2nd order tributaries due to economic consideration and efficiency.
- Preventing waste entering the main waterway, the Citarum river.
- Capture the river waste entering or release out from the protected area Easy in maintenance.

By using Computational Fluid Dynamic (CFD) and Particle Tracing modules, some RTI alternatives are simulated and analyzed. The results of this study can be used as a reference stuff for decision making on RTI planning and development in the near future

2. The Idea, Methods and Site Consideration

The idea of RTI comes from observing the condition of the river waterway itself. At some river bends, the trash is trapped due to the turbulence of the river stream. This condition is attempted to be further developed through simulation to obtain the most efficient forms in trapping the waste.

2.1 Preliminary design of natural wateway shape reform for the RTI

The natural form of the Citarum river and its tributaries mostly is a straight line shape, bend shape and U-type shape. At first, a number of 3D RTI model were built, rebuild or refined through the simple simulation to get the appropriate model. The best model is stright line shape that should be developed further. In figure 1 shows the concept of RTI (a) and the concept of its implementations on the bend shape river (b) and U-type shape river (c).
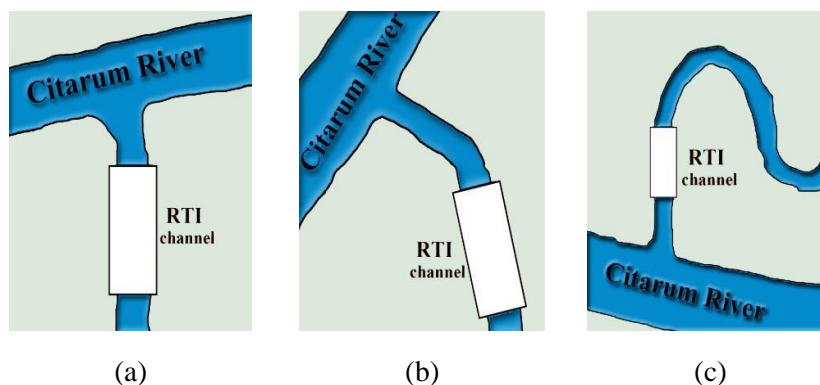

Figure 1. The concept of RTI implementations.

2.2 Simulation using CFD and Particle Tracing module

The Comsol Multiphysics was used in this study. The RTI is modeled using combinations of CFD and Particle Tracing modules. A number of 3D RTI model were built, rebuild or refined through the simulation to get the appropriate model. The support data are obtained from related institutions, Google Earth, direct observation and photography. These data include the width and depth of the river, volumetric flow rate, maps and topography of the area, and due to the assumptions that the waste brought by the water flow is a particle then the average volume size of waste and its density are needed to know.

2.3 Consideration of placement location

Consideration of RTI model placement should be attention to the natural river formation and utility that already exist near the site.

- Trash collected by RTI must be lifted out by the use of a crane and and moved the waste into a garbage truck. These trucks are used for picking up waste and then moving it to landfills or other location. Thus, the RTI site should be near to the available roadway.

- The site should be near to the main stream river, the water reservoir or the ocean, to protect the main stream river, the reservoir or the ocean from the waste entering into it.
- The site should be near to the location that has the densest population, due to probability of produce more solid municipal waste.
- The site should be utilize the existing river bends to minimize work and construction costs. The site can be used as a temporary garbage dump for nearest community

Another consideration is a local government issue, due the Citarum river is across many local region so it's not their pure responsibility. By assuming that every local government is responsible for their territory, hence it should be their responsibility to capture the river waste entering or to release out from their territory.

3. Result and Discussion

3.1 The selected site and data praparation for modelling the RTI

The selected site is Bandung city region, the capital of West Java province. Bandung city was chosen because the population is densest and 60.1% of its population used to dispose solid municipal waste into the river [6]. Bandung has 42 tributaries, 14 of these are 2nd order tributaries that crossed border region. Figure 2 shows the site map of Bandung (6°55'4.27"S, 107°37'7.35"E) has crossed by tributaries which is a direct discharge into the Citarum river. Figure 3 shows the basic river type in the Bandung region, consisting of 3 compbination of unconfined single-thread: straight (figure 3a), sinuous (figure 3b) and meandering (figure 3c) [7].
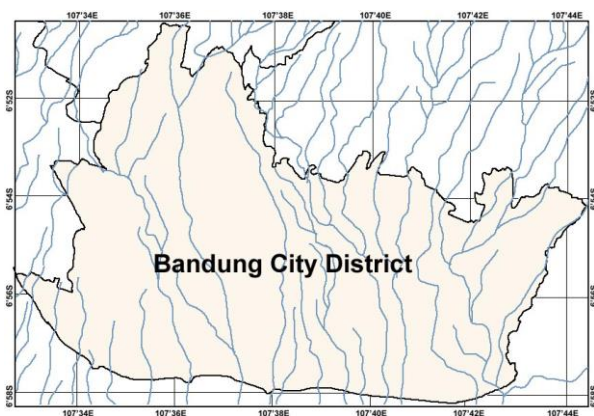

Figure 2. Map of Bandung City District that crossed by many 2nd order tributaries.
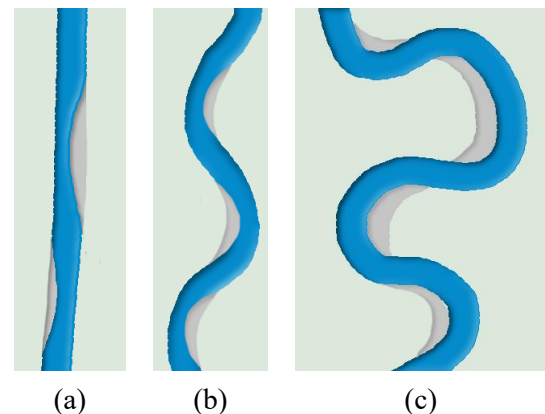

(a)   (b)   (c)

Figure 3. Basic type of river of Citarum tributaries; straight (a), sinuous (b), meandering (c)

The downstream part of the Citarum tributaries mostly follow type F in the morfology classification of Rosgen method [8], where it's wide, shallow, entrenched meandering, less likely to be flooded. The flooding that has happened recently is caused by the waste that clogs the stream.

Table 1 shows the data of 14 tributaries discharge directly to Citarum, daily average discharge of 2.94 m^3/s and an average width (W) of 7.9 m. The ratio of width at bankfull (W_{bf}) divided by means of depth at bankfull (D_{bf}) will determine the velocity and shear stress distribution within the waterway.

$$\frac{W}{D} = \frac{W_{bf}}{D_{bf}} \tag{1}$$

With the ratio $W/D < 12$ according to Rosgen, then the depth (D) could be assumed as 2 m, and the slope range are less then 2%.
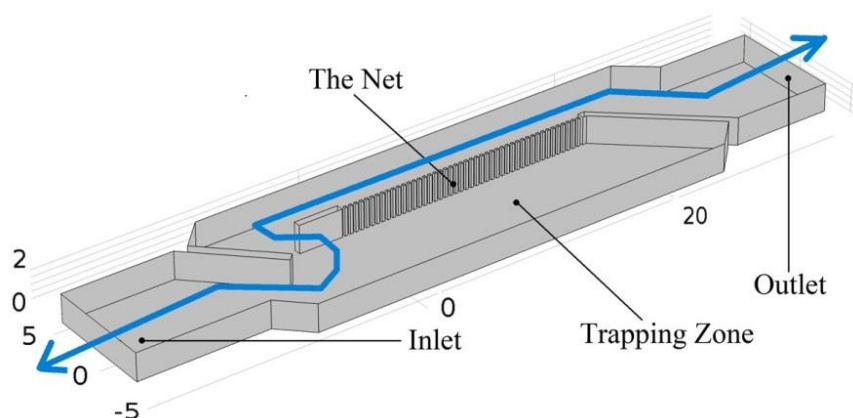
Table 1. The 2nd order Citarum tributaries that crossed the Bandung city region[*]

Name of 2rd order Tributaries	Length (km)	River Width (m)		Waster Discharge (m³/s)	
		Max	Min	Max	Min
Cikapundung	15.5	6	12	250	12
Cipalasari	4	3	5	20	0.15
Cipamokolan	18	5	15	40	25
Cidurian	20	6	12	83	1.25
Ciwastra	3.5	3	6	18	0.4
Citepus	6.5	2	15	50	0.1
Cibedug	5	5	8	15	0.1
Curug Dog-Dog	2.5	5	8	25	0.15
Cibaduyut	2.25	4	6	20	0.15
Cikahiyangan	1.6	3.5	4	15	0.1
Cibuntu	4	3	4.5	30	0.15
Cianting	4	3	4.5	15	0.7
Cigondewah	3	2	3	36	0.7
Cibeureum	12	6	8	38	0.75
		Average :	7.9	Average :	2.94

[*] Data Sungai dan Anak Sungai [9]

3.2 The RTI model

Due to it is still functioning as a means of transportation, RTI's design does not completely cover the river with a net, but utilizes the river currents to direct the waste into the net. The blue line in figure 4 shown the river surface area that can still be used for transportation.

Figure 4. 3D model of the RTI, unit in meter.

By setting the width of the RTI (*W*) is 8 m, depth (*D*) is 2 m and the water discharge (*Q*) is 2.94 m3/s, then *U* can be calculated by the equation (2):

$$U = \frac{Q}{W \cdot D} \tag{2}$$

where *U* is the velocity of inlet water of 0.18 m/s.

Based on the value of *U* above, then Reynold number (*Re*) can be calculated using the equation (3):

$$R_e = \frac{U \cdot L}{v} \tag{3}$$

where L is corespoding to D and v is the kinematic viscousity of water ($1 \cdot 10^{-6}$ m^2/s). Re is very high ($Re=3.6 \cdot 10^5$, $Re > 2000$), hence the flow must be modeled using a turbulence model, which in this case the k-ε turbulence model is used. All boundaries in figure 3 are walls, except the inlet and the outlet. The boundaries are assigned as a no-slip. No-slip boundry means the fluid will have zero velocity relative to the boundary. Developed flow is used as an inlet boundary condition and constant pressure is prescribed at the outlet boundary.

In this case, the river waste is considered as a particle. In COMSOL Multiphysics, it is possible to do particle tracing by compute the flow field first, then, as an analysis step, calculate the motion of particles. External forces such as gravity force and drag force are also used in computing, The drag force that affect to the large particles is computed using Schiller-Neumann law [10]. Most river trash is floating debris that come from agriculture and solid municipal waste, its assumed as a large wood particle with average density of 680 kg/m^3 [11] and assumed as a spherical shape with a diameter of 0.3 m. A spherical shape is chosen due to it's unique in that it presents the same area to the oncoming fluid whatever its orientation [12].

3.3 The simulation of the RTI
In figure 5 shows the velocity and velocity vector at the top surface of the channel. The incoming water from the inlet hits the first baffle which splits the stream and creates a strong recirculation to the trapping zone. The stream that brought the waste continues to pass through the net and leave the waste trapped in the net. The velocity magnitude increased while the stream passes through the second baffle, and then flow to the outlet.
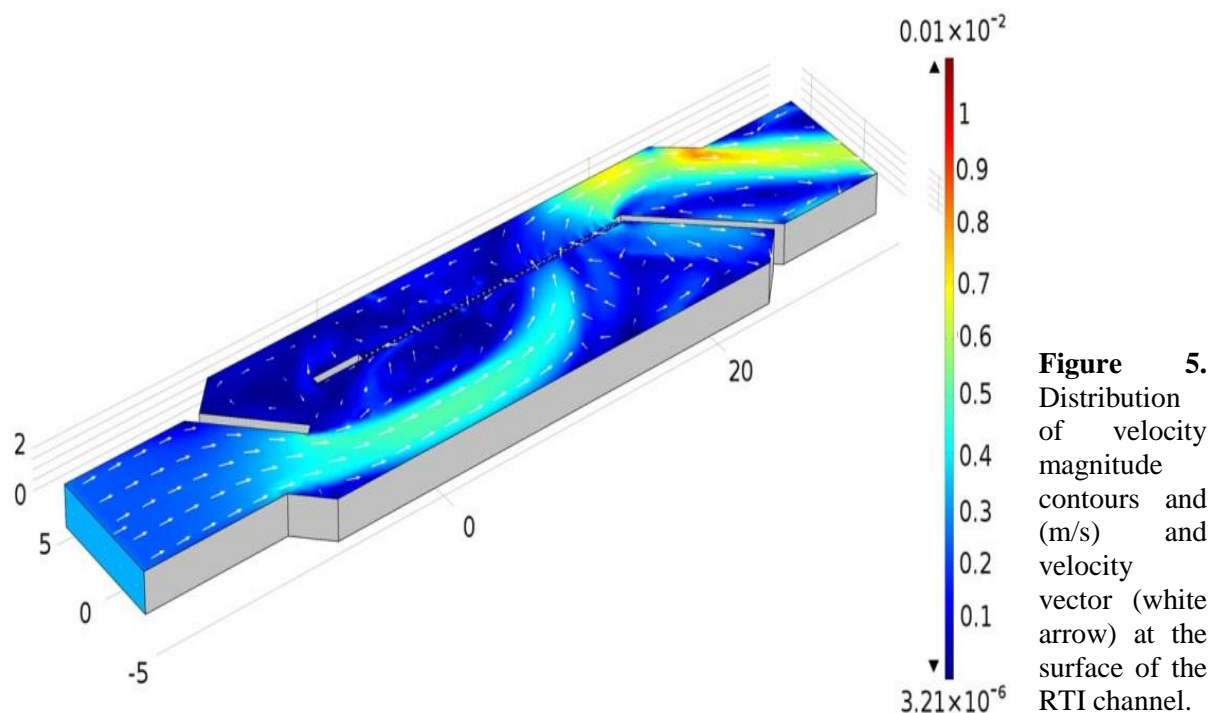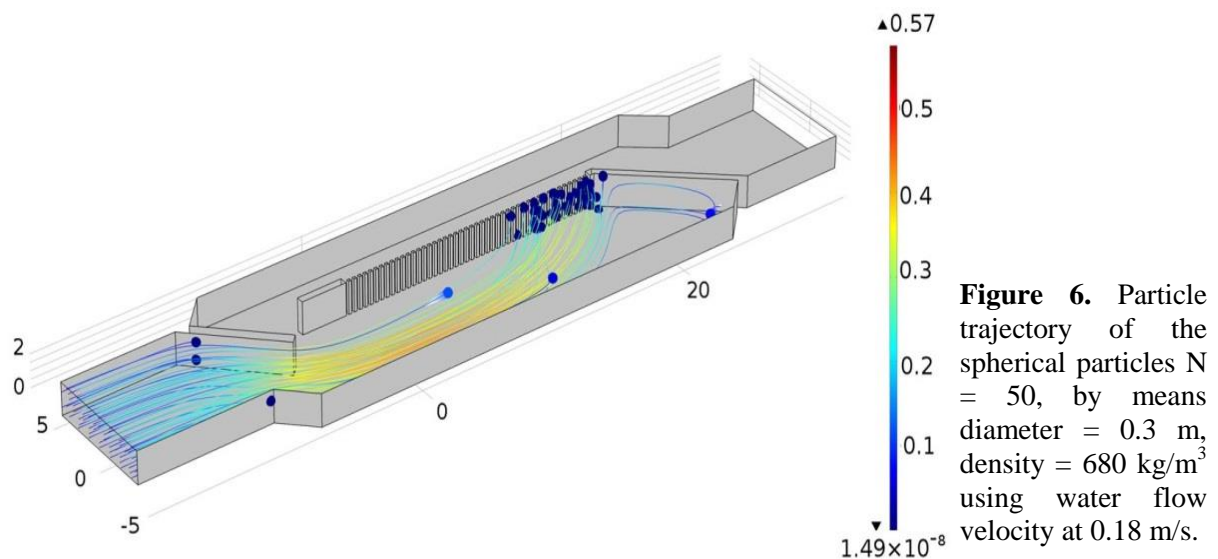

Figure 5. Distribution of velocity magnitude contours and (m/s) and velocity vector (white arrow) at the surface of the RTI channel.

In figure 6 shows that all the particle are trapped. 3 particles are trapped at the inlet gate of the channel and the rest (47 particles) are trapped at the net at the trapping zone. Motion of particle in the water flow are represent by the trajectory line. The color expression of the trajectory line are proportional to the particle velocity in m/s.

Figure 6. Particle trajectory of the spherical particles N = 50, by means diameter = 0.3 m, density = 680 kg/m^3 using water flow velocity at 0.18 m/s.

3.4 The implementation of the RTI
Figure 7 shows an example of implemtation of the River Trash Interceptor on the site. The excavator could lift the waste into the stockpile or directly lifting into the garbage truck. The waste stockpile could be used as a temporary garbage dump for the nearest community.
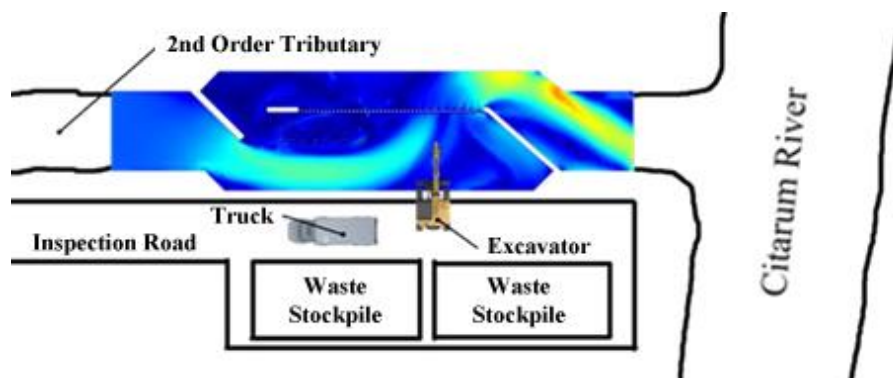

Figure 7. The implementation of RTI on site, an example

4. Conclusion
From the simulation results, almost all floating trash can be intercepted by this RTI design. The straight line design is chosen, due the river with this form are commonly found in Bandung district, and also because it is effective to use the land beside the river. However, it is necessary to find a low slope site for RTI implementation.

The model design of RTI is effectively used to protect the region that crossed by the 2nd order tributaries, to trap the waste entering or release out from the region. Almost all the waste that has a size bigger than the net could be trapped. It's also economically due to the width of river that are less than 10 meters. As it is still within the crane arm to lift up the collected waste, but it is also possible to apply on a larger scale (1st order river) such as in the mouth of the reservoir or the estuary to the sea.

In the future, it is expected that RTI can be applied in all local governments within the West Java province, because the construction size is small and every local government should be responsible to manage and protect their respective areas from the waste. The design of RTI is solely used for decision-making considerations, actual implementation must be redesigned, remodeled and simulated by taking into account the actual site condition.

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