MATHEMATICAL MODELLING OF SEDIMENT TRANSPORT AND ITS IMPROVEMENT IN JATILUHUR IRRIGATION SYSTEM

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ABSTRACT

When providing irrigation water to the paddy fields, optimal performance in terms of adequacy, reliability and efficiency of the irrigation system are needed. Transport of sediment has significant impact on system performance particularly related to sediment deposition in the canals, which will likely modify the canal morphology. To study the morphological changes, a mathematical model is one of the ways to simulate sediment transport processes and its effects upon the canal form.

This paper aimed to study the application of the SETRIC to simulate sediment transport processes in Jatiluhur irrigation system, case study Bekasi Weir Irrigation Scheme. The model helped to predict sedimentation along the canal networks for certain flow conditions. The irrigation scheme features including canals, control structures, off take structures, discharges, and incoming sediment will be represented in the model. Some findings that have been obtained from the study are: (1) Bekasi Irrigation System has possibilities of high deposition of sediment; (2) SETRIC model seems as promising tool to be used in assessing the irrigation system performance particularly for morphological changes in the canals network.

Keywords: *sediment transport, SETRIC program, canal morphological changes*

INTRODUCTION

As the consequences of rapid population growth in Indonesia, demand for rice as staple food becomes essential. In 2008, the total population reach 230 million with growth 1.5% per year (*www.bps.go.id*). Therefore, improvement in rice production and its sustainability in term of optimization upon existing area and new land development will be needed. Irrigation and drainage will likely have important role to deal with how to enhance food production (Schultz, 2005).

There are many challenges to optimize and to improve productivity of the existing irrigation system. One of the main challenges in this irrigated agriculture is a system performance which is not fulfilled its design capacity. There are many causes for this low performance e.g. damage on the canal which increases water losses trough the leakages and sedimentation in the canal which reduces canal capacity.

Jatiluhur Irrigation System with the total service area 242,000 ha is one of the strategic irrigation schemes in Indonesia as it produces about 40% of West Java Production and 5% of national rice production. As other irrigation scheme in Indonesia, sedimentation in irrigation system becomes a problem due to lack of regular maintenance. In addition, there is also increasing of sediment in the irrigation water which is related to erosion and land use changes in upstream catchments area.

The sediment can be classified into cohesive and non-cohesive. Cohesive sediments mean that there are high physical-chemical bonds between the sediment particles. Contrary for non-

cohesive sediments, these bonds almost do not exist. Hence, sediment movement of the cohesive sediments is depends on interaction between the particles, and for non-cohesive sediments, the size and weight of the each sediment particle is the main factors (Mendez, 2007). This paper will primarily discuss about the non-cohesive sediments transport.
Sediment transport in the supply canal has significance impacts for operation and maintenance of the irrigation systems. As water flow has ability to convey the sediment, it can either erode the canal surface or silt up the canal. These two events will likely increase the cost for maintenance and due to decline the canal capacity; disturb water delivery. Therefore, proper understanding of sediment transport processes will be helpful for proper operation and maintenance plans and the related activities.

Mathematical model can be used as a tool to get better knowledge regarding transport of sediment process. The model will help to predict sedimentation and erosion along the canal networks for certain intended flow condition. In this study, SETRIC software was used as a tool for modelling of sediment transport.

PROBLEM DEFINITION

In general, as water extracted from the river to irrigation scheme, the sediment is diverted as well. Fine material will be located in to the field while the coarser ones might settle and deposit in the canals. It is needed to ensure that this settled sediment takes place in the desired location which maintenance work will be easier to carry out. Effective performances of the silt trap / sediment control will likely help in reduce the size and concentration of the sediment when water enters the canal networks.

Bekasi Irrigation System located in the low elevation. It has elevation from 20 m to 0 m above mean sea level with quite gentle slope. Due to the study area location, the area is the downstream part from either Bekasi River or West Tarum Canal perspective. Therefore, naturally the sediment concentration in the both of water sources is relatively moderate to high.

From this situation, sedimentation in the irrigation canal becomes a problem that quite challenging to handle. Proper canal maintenance and canal operation becomes essential to keep performance of the irrigation system as intended. As the result, deposition of sediment in the canal is one of the causes for low performance of the scheme. Regular maintenance faces the problem due to difficulties in predicting sediment deposition in the canal and makes the budget applied for maintenance not optimal. Mathematical models seem probable to represent the sediment transport processes in the real field.

DESIGN OF IRRIGATION CANAL

According to FAO, the design objective of an irrigation canal is to make the bottom slope (So) and dimension of the canal in such a way that during certain period, sediment inflow and outflow of irrigation canal is balance. In addition, Chang stated that canal slope and geometry should be able to keep the sediment in equilibrium condition (Mendez, 1998).

Furthermore, as cited from Mendez (1998), Dahmen stated that the design and operation of irrigation system should be done such a way that:

- able to convey water as designed water level
- prevent erosion in both bed and side of the canals

- prevent sediment deposition in the canals

According to Mendez (1998), Ranga Raju categorized three phases of the canals design:

- canals with rigid boundary
  the canal is designed base on velocity in which no sediment will settle.
- canals with erodible boundary and carrying clean water
  the canals is designed at cross section where no movement of bed material. The result expected is smallest cross section with maximum velocity without produce scouring on canals bed
- canals with erodible boundary and carrying water with sediment
  the canals should be able to convey water and sediment without erode the canals bed. As result, the irrigation canals create balance between sediment inflow and sediment outflow for intended period. This situation means that canal is stable.

Flow control structures in irrigation canals

In irrigation canals, from operational point of view, there are four major types of structures exist (Paudel, 2009):

- fixed (weirs and orifices);
- on-off (shutter gates);
- adjustable (stop logs, undershot gates, movable weirs);
- automatic (automatic upstream and downstream water level control structures).

From a hydraulic point of view, the irrigation structures can be categorized into:

- free overflow/overshot structures (weir, Romijn Weir, which mainly used in Bekasi Irrigation Scheme, Flumes, Sharp Crested Weir);
- underflow/undershot structures (orifices, gates);
- pressurized flow structures (culverts, pipes).

SETRIC PROGRAM TO MODEL SEDIMENT TRANSPORT IN IRRIGATION CANAL

SETRIC program was initiated by Mendez in 1998 who prepared the concept and mathematical formula for the model program. Advance development is continued by Paudel in 2002, and Depeweg and Paudel in 2003, to make it relevance to represent the real field problem. In 2009, SETRIC validation with field data and utilisation to evaluate design and water management aspects is carried out by Paudel.

SETRIC is one-dimensional model in modelling the sediment transport. The water flow in one-dimensional model is schematised as a quasi-steady flow and gradually varied flow. As one-dimensional model, SETRIC use predictor-corrector method to solve the flow equation. For actual sediment concentration simulation at any point under non-equilibrium conditions, Galappatti's depth integrated model is used. According to Paudel (2009) as he quoted from Wang and Ribberink, this Galappatti's integrated model has two advantages which are: (1) it does not use empirical relations in model derivation and; (2) it can use nearly all bed boundary condition. In addition, Ribberink also learned that Galappatti depth integrated model includes the boundary condition close to the bed, therefore, there is no requirement for formulate the empirical relation of sediment/erosion rate near the bed (Paudel, 2009).

Modified Lax's method is used to resolve the mass balance equation for the total sediment transport with assumption that the sediment concentration is in steady state. For the prediction of the equilibrium concentration, it can select one of the three sediment transport predictors; Brownlie method, Engelund and Hansen method or Ackers and White method. Roughness in the bed and sides of the canal is computed separately. The bed roughness is depends on water flow and characteristic of the sediment while the side roughness is influenced by the vegetation. The van Rijn method is used to compute the bed roughness. The method is based on the bed form and sediment size. After that, the side canal effect is considered in computation of the equivalent roughness (k_{se}) (Méndez, 1998).

Sediment transport in general

The aim of canal design related to transport of sediment is to minimize the occurrence of either erosion or deposition in the irrigation canal network. The idea is that the incoming sediment from main intake (normally from the river) supposed to be brought to the field or placed at intended location. The source of sediment normally is river from where the water extracted. The small discharge of the irrigation canals, compare to the river discharge, make this aim is quite tricky.

Water supplied to the irrigation system is different during the irrigation season. This is caused by the different crop water requirement relate to its growing stage, and rotation in water delivery. Therefore, the flow pattern in the canal becomes non-uniform. As sediment transport is greatly depends on flow parameters, any change in flow pattern will have significant effect on sediment transport capacity of the canal. Hence deposition or erosion pattern will also fluctuate depending on the flow type at the moment. The major concern should be put on whether balance occurs at certain section, in other words the sediment deposit at one time and eroded at other time. The canal can be said to be stable if this balanced condition could be sustain through appropriate operation and maintenance.

There are three sediment transport form which are:

- Wash load; consists of very fine particles which are conveyed by the water. These particles do not present on the bed. Therefore the prediction of wash load transport is not allowed if it based upon the knowledge of bed material composition. Hence, wash load will not be considered in this research;
- Bed-load; the part of the total load which almost has continuous contact with the bed. Transported by rolling, sliding or jumping;
- Suspended load; the part of the total load which is moving without continuous contact with the bed as the result of the disturbance of the fluid turbulence. (Liu, 2001).

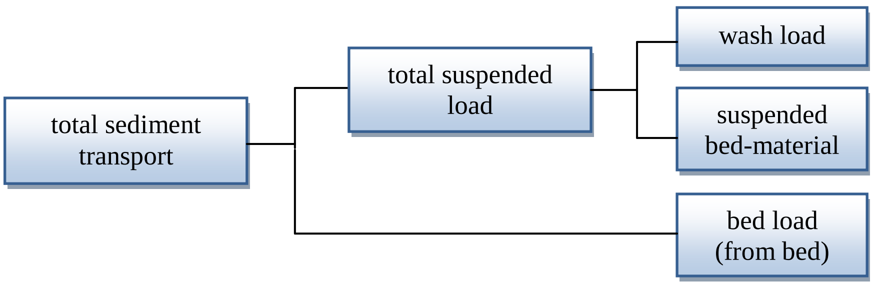

Figure 1 - Sediment transport classification

Governing equations

There are two aspects to be considered in schematizing the water flow in the irrigation canals. Firstly, the operational aspects where the water flow becomes non-uniform and unsteady due to changing in water requirements and gates operational to fulfil the water demand and to keep water level as it required for the fields needs. Secondly, the sediment transport aspects, where the changes in water flow in time and space are faster than changes in morphology of sediment.

As quoted from Mendez (2007), according to Cunge et al, the interrelation between water flow and sediment transport can be illustrated as one-dimensional event without changing in the shape of cross section as follows:

Hydraulic aspects:

- Continuity equation for water movement: $\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$
- Dynamic equation for water movement: $\frac{\partial h}{\partial x} + \frac{V^2}{C^2 R} + \frac{\partial z}{\partial x} + \frac{V}{g}\frac{\partial V}{\partial x} + \frac{1}{g}\frac{\partial V}{\partial t} = 0$

These two equations describe the conservation of mass and momentum which also known as Saint Venant equation for continuity and dynamic unsteady flows. These equations are water flow related. For sediment related, the equations are given below.

- Friction factor predictor as a function of: $C = f(d_{50}, V, h, S_o)$
- Continuity equation for sediment transport: $(1-p)B\frac{\partial z}{\partial t} + \frac{\partial Q_s}{\partial x} = 0$
- Sediment transport equation as a function of: $Q_s = f(d_{50}, V, h, S_o)$

These five equations related each other, for example: roughness coefficient is influenced by water flow while sediment transport is affected by the water flow.

The unsteady flow condition in the irrigation canal is assumed to be quasi-steady, hence $\partial A/\partial t$ and $\partial V/\partial t$ can be neglected. Therefore, the continuity equation and dynamic equation become:

$\frac{\partial Q}{\partial x} = 0$; $\frac{dh}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$;with $Fr = \frac{V}{\sqrt{g.h}}$

In uniform flow, there is no change in water depth, hence:

$\frac{dh}{dx} = 0 \rightarrow S_o = S_f$

Then, the uniform flow equation will be:

$v = \frac{1}{n} R^{1/3} S_f^{2/3}$ or $v = C\sqrt{RS_f}$

Sediment transport under equilibrium

Sediment transport is under equilibrium conditions when water flow brings sediment concentration as the flow capacity to transport the sediment. Therefore, there is no deposition or erosion takes place (Vabre, 1996).

There is no equation which prevails universally in determining the sediment transport capacity. Some of methods which commonly used in sediment transport computation are: Brownlie, Ackers-White, and Engelund-Hansen.

- Engelund and Hansen method

The Engelund and Hansen method is based on the energy considerations and relation between the transport and mobility parameters.

- Modified Ackers and White method

Ackers and White described the sediment transport in terms of three dimensionless parameters i.e. D* (grain size sediment parameter), F_{gr} (mobility parameter) and G_{gr} (transport parameter).

The coefficients *c* and *m* were modified later (HR Wallingford, 1990, Ackers, 1993). The reason is the original relations predicted transport rates were viewed too large for fine sediment ($d_{50} < 0.2$ mm) and for coarse sediment ($d_{50} > 2$ mm).

- Brownlie method

Brownlie's method is based on a dimensional analysis and calibration of a wide range of field and laboratory data, where uniform conditions prevailed.

Sediment transport under non-equilibrium

In the other hand, non-equilibrium conditions in sediment transport are when water flow brings sediment concentration different from the flow capacity to transport. There are possibilities of deposition when sediment concentration transported is higher than the transport capacity (Vabre, 1996). This can occur in both uniform and non-uniform flow conditions.

In non-uniform flow, the sediment transport capacity keep changing due to difference of flow parameters along the canals. The consequence is the need to modification of sediment concentration in the water flow either continuous deposition or entrainment on/of the bed of the canal. These adjustments processes occur more or less instantly for bed load and relatively slow for suspended load. The reasons are, for the bed load, transport mode occurs next to the bed, while it takes time and space to settle down for the suspended load. The time lag needed to adjustment process makes the sediment transport in non-equilibrium condition (Paudel, 2009). In SETRIC, Galappatti's integrated depth model has been used to solve sediment transport under non-equilibrium condition.

Galappatti equation base on two-dimensional diffusion-convection equation which can be written as follows:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + w\frac{\partial c}{\partial z} = w_s\frac{\partial c}{\partial z} + \frac{\partial}{\partial x}\left(\epsilon_x\frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial z}\left(\epsilon_z\frac{\partial c}{\partial z}\right)$$

In Galappatti's depth integrated model, sediment coefficient in horizontal direction (ε_x) and water flow velocity in vertical direction (w) is neglected, therefore the equation will be:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = w_s\frac{\partial c}{\partial z} + \frac{\partial}{\partial z}\left(\epsilon_z\frac{\partial c}{\partial z}\right)$$

In addition, the concentration (c) in vertical, horizontal and in time (x,z,t) is expressed as a depth averaged concentration ($c_{x,t}$). The schematisation of concentration in two-dimensional model and schematisation of concentration in depth integrated model is illustrated in the following figure are illustrated in the following figure:

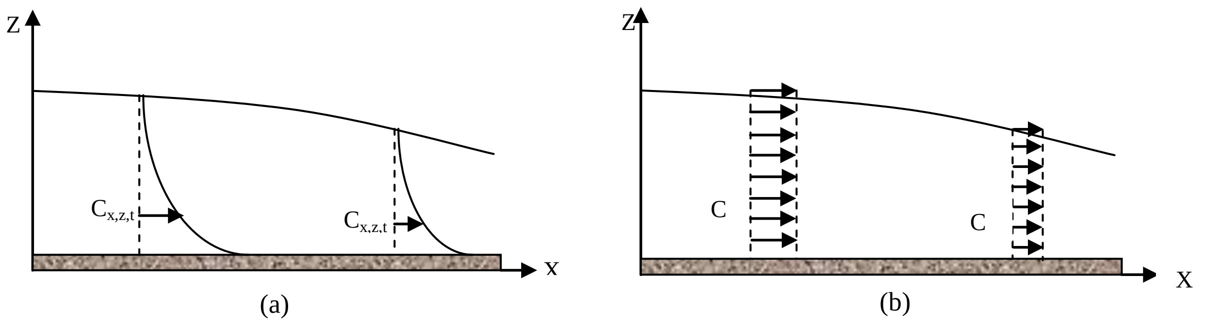

Figure 2 – (a) Schematisation of two-dimensional suspended sediment transport model; (b) Schematisation of depth integrated model

For uniform flow under non-equilibrium condition, the sediment concentration equation of Galappatti's depth integrated model can be written as:

$$c_e = c + T_A\frac{\partial c}{\partial t} + L_A\frac{\partial c}{\partial x}$$

Adaptation length and adaptation time is the interval in length and in time required for a concentration to reach equilibrium concentration. After some formula derivation, the final formula for total sediment transport under non-equilibrium condition is:

$$C = C_e - (C_e - C_0)exp - \frac{x}{L_A}$$

Morphological changes of the bed level

As mentioned previously, the sediment mass balance equation is:

$$(1-p)B\frac{\partial z}{\partial t} + \frac{\partial Q_s}{\partial x} = 0$$

In SETRIC, this equation is solved using modified Lax method which expressed as:

$$z_{i,j+1} = z_{i,j+1} - \frac{1}{B(1-P)}\left[\frac{Qs_{i+1,j} - Qs_{i-1,j}}{2\Delta x} - \frac{1}{2\Delta t}\left[(\alpha_{i+1,j} + \alpha_{i,j})(z_{i+1,j} - z_{i,j}) - (\alpha_{i,j} + \alpha_{i-1,j})(z_{i,j} - z_{i-1,j})\right]\right]$$

Eq. 0-1

For upstream boundary:

$$z_{i,j+1} = z_{i,j} - \frac{1}{B(1-P)}\left[\frac{Qs_{i+1,j} - Qs_{i-1,j}}{2\Delta x} - \frac{1}{2\Delta t}\left[(\alpha_{i+1,j} + \alpha_{i,j})(z_{i+1,j} - z_{i,j})\right]\right]$$

For downstream boundary:

$$z_{i,j+1} = z_{i,j} - \frac{1}{B(1-P)}\left[\frac{Qs_{i+1,j} - Qs_{i-1,j}}{2\Delta x} + \frac{1}{2\Delta t}\left[(\alpha_{i,j} + \alpha_{i-1,j})(z_{i,j} - z_{i-1,j})\right]\right]$$

BEKASI WEIR IRRIGATION SCHEME AS PART OF JATILUHUR IRRIGATION SYSTEM

Bekasi Irrigation Scheme is a part of Jatiluhur Water Resources Systems. The water source is extracted from Bekasi River with supply from West Tarum Canal of Jatiluhur System. The Bekasi scheme has total service area of ±5700 ha with paddy / rice as the main crop. The following figure shows the sketch of scheme.

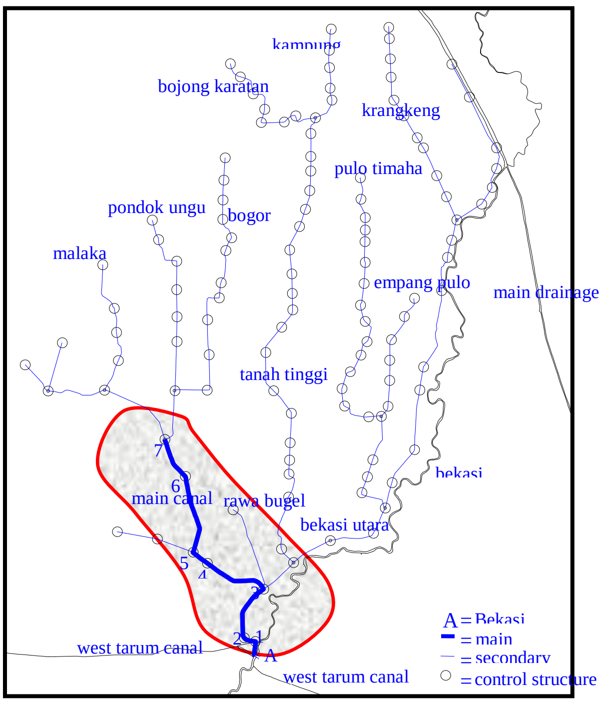

Figure 3 - Bekasi Irrigation Scheme

The main canal (bold line) will be selected to be modelled using SETRIC. Number 1 to 7 is the nodes where the control structures located, and later will be represented in "structure tab" of SETRIC program. The shading area is the "area" which will be schematised and simulated later.

Operational of the system

Intake structure consists of three gates of undershot type and outgoing water flow of the silt trap is controlled using Crump de Gruyter type of structure. To the downstream direction, most of the water control structures use removable sharp crested weir while Romijn weir mainly being used for tertiary off takes structures.

Canal operation is a continuous operation where the upstream control is used for the flow control. The upstream control means that the water level regulators maintain a constant water level at the regulators. The decision making procedure on the water allocation to the tertiary off takes is imposed allocation where the irrigation management decides the water allocation. However, in case of special request from the farmers or water user association, the management may adjust the water allocation to fit the request.

According to design condition, the scheme has service are of ± 12,000 ha. It also has 5 (five) groups of planting which are Group I, II, III, IV, and V. The different among the groups is the starting schedule. There are 15 days differences for each group in starting the season. Due to land use conversion from agriculture into settlement, currently only three groups of Group III, IV, and V left for irrigation, with service area of ± 5,700 ha.

There are 2 (two) cropping seasons a year, rain season (*rendeng*) and dry season (*gadu*) with cropping pattern is paddy-paddy. In rain season, water is actually sufficient to apply without group system. However, one of the aims of group system is also to facilitate the farmers to work in the fields so they can shift the equipment to the next field after one field is finished. The reason are (1) most of the farmers are the labourers of the land owner, (2) it needs cooperative effort among the farmers to work on the field; hence applying the group system is useful. In the dry season, beside to facilitate the farmer, group system is also applied to ensure adequacy of water delivery.

Field data

a. Suspended load

The lab result for sampling analysis result in sediment concentration of 415 ppm

b. Grain Analysis

The samples are taken from deposition of sediment on the bottom of the canal from point A and B, C, and D. At point A, there is no sample available due to the sampling location near the main intake which turbulent flow occurs. From laboratory grain analysis, the diameter of the sediment is obtained. Then, the mean value of D_{50} of 0.019 mm is used in sediment input in SETRIC model.

c. Maintenance data

Table 1 - Sediment removing work records

No.	Year	Quantity (m^3)	Unit price (Rp./m^3)	Total Costs (Rp)
1.	2004	8,790	20,000	175,800,000

2.	2008	3,616	24,200	87,507,200

Beside these works, there are also flushing work which has been done yearly using high discharge to remove the sediment deposition in the silt trap. Nevertheless it cannot wash away all sediment because the optimum discharge needed could not be applied. The reason is management also has to keep amount of discharge continuously to West Tarum Canal (Kalimalang) for drinking purpose for the city of Jakarta. Therefore, using heavy equipment is still the available option.

SIMULATION AND RESULTS

Schematisation

The main canal which has important role in conveying irrigation water to the secondary off take is selected to be modelled. The main canal is consists of seven reaches and seven control structures. The drawing of the main canal is depicted by figure 6.1 below.

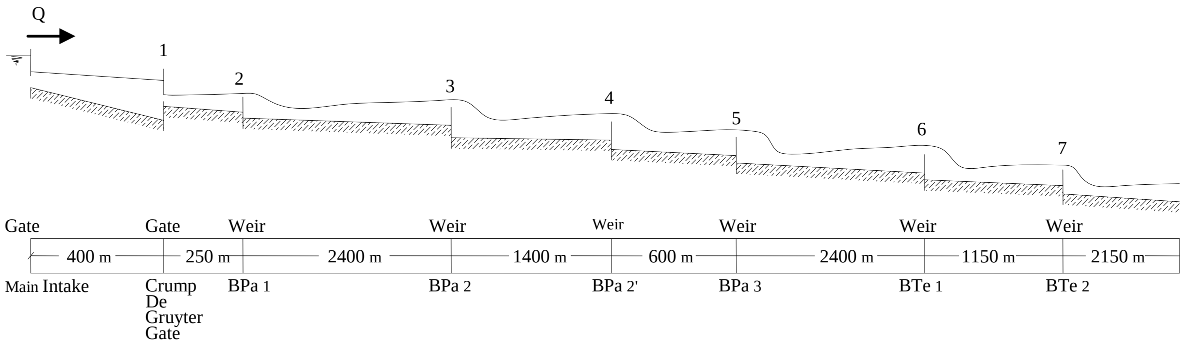

Figure 1 - Main canal longitudinal section

Canal dimension input

This table for canal properties including length, bed width, bed slope, side slope and bed elevation. For SETRIC model, the canal propertied is modelled at the design condition. The features including roughness, bed slope, side slope, and bed elevation is taken base upon asset inventory data.

Irrigation methods, sediment input and lateral information

The discharge and sediment input are set for one year of 25 time steps with 15 days length each. The 15 days various discharges are schematized into one average discharge. For sediment concentration, it is schematized into 15 days average as well. For rainy season, decision in the sediment concentration value is based upon the field measurement which has been carried out at 3rd December 2009. The additional output calculation of SETRIC model also has set for every month. The upstream boundary is discharge rate and the downstream boundary is water depth of the last canal section. The procedure is the same in simulating the three-year model.

For sediment it used different sediment concentration appropriate with change of discharges. There are three available options for sediment transport capacity predictor, Brownlie, Engelund-Hansen, and Modified Ackers-White. The selection of the method should consider in what condition the methods were developed. The Engelund-Hansen is suitable for D_{50} between 0.19 mm and 0.93 mm, while Ackers-White method was developed under condition grain size greater than 0.4 mm and the water depth of 0.4 m. Hence, in this study, the Brownlie method was selected based upon the consideration that the sediment size and water depth of Bekasi Irrigation Scheme is more suitable with the Brownlie method. Furthermore, the Brownlie and Ackers-White method likely gave the best result of sediment transport prediction in irrigation canals (Mendez, 1998).

There are 2 lateral from the intake to control/off take structure BTe 2. Both of them are actually secondary canal branch of the main canal which we treat as lateral in SETRIC model for this main canal.

Control structures

In this main canal reaches, there are 7 structures in the 7 node (see Figure 6.1). The details as follows:

- **Structure 1; at the node number 1 (Nowo Gate)**

  Nowo Gate (after silt trap) has Crump De Gruyter structure with 4 (four) gates. From the 4 gates, only 3 gates are operated because the water requirement for existing paddy field has been reduced compare to design condition. In the model, this structure is treat as undershot type of structure with 1 (one) gates which has width of summation of three gates. The gates control is set as .fixed gate opening of 0.3 m and crest height is 3 m above the upstream bed.

- **Structure 2 – 7; at the node number 2 – 7 (BPa 1 – Bte 2)**

  The control structure in BPa 1 to BTe 2 are sharp crested weir made of stack of wood bar pieces (called *skot balok*) which also known as stop log type. The bar stack can be adjusted according to the requirements by removing or adding the wood bar piece. This kind of sharp crested weir is commonly used as water level control structures in the Bekasi irrigation system. In SETRIC model, this type of weir is represented in overflow type of structure as sharp crested weir.

  At node number 3 and 7, there are secondary canal branch to the east/right direction named Bekasi Utara (BUt series). This secondary canal is treated as lateral number 1 and 2 in SETRIC lateral input.

Weed information

This tab contain information of weed factors including growing time, maintenance interval periods, constant parameters (gravity, water viscosity), and sediment parameter. The weed factor values are determined according table 4.2 about weed factor of different type vegetation. During the field observation, the weeds in the canals can be categorized into *Low*, hence, it has weed factor of 1.25 - 1.5. The time step for model is set for 2 hour and length step of 100 m

Three-years model results (actual-present condition)

From results of three-year model, it produces the similar pattern result with one-year model. The differences are in amount (quantitative) of the units in parameters. For example, comparison bed level changes between one year and three years model. The pattern and the location of the changing occurrences are similar and the different is in how much the bed level is modified.

The result of three-year simulation as follows:

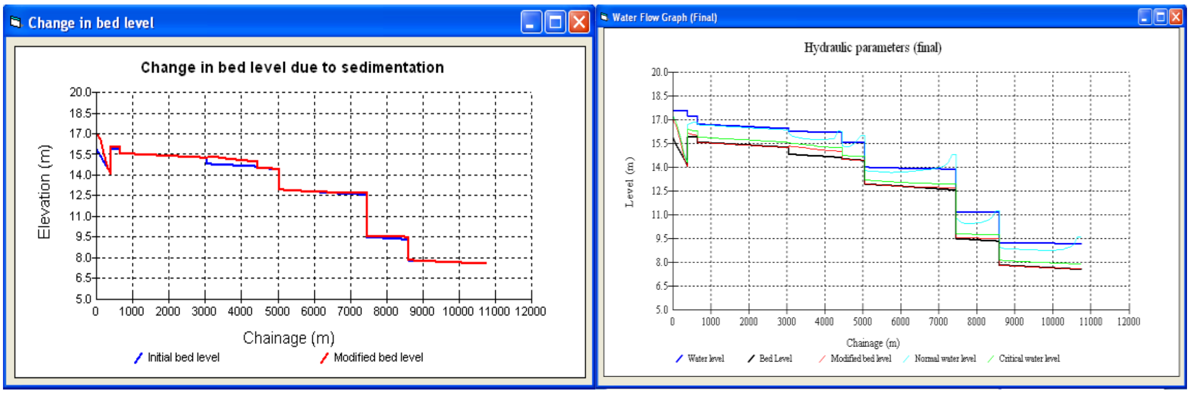

Figure 2 – Hydraulic parameter and changes in bed level after three years

To test what the effect of this accretion of the canal bed to the performance, the discharge capacity of the canal is calculated and compare to the initial canal's discharge capacity.

Output analysis and interpretation

According to simulation results, the sediment deposition mainly takes place in the silt trap, first canal section after the silt trap, and at the section between +3050 m and +4450 m. Hence, it is suggested the management should pay attention at these sections.

a. Silt trap, 0 - +400 m (main intake - Nowo gate)

The silt trap is aimed to deposit the sediment to minimize amount of sediment entering the canal network. It needs to be cleaned regularly so the sedimentation volume would exceed the silt trap capacity. The SETRIC output of sedimentation final results is presented below. Note that the tables of result have been delimited into the sections where the sedimentation occurs.

Table 1 - Sedimentation in the silt trap

One-year model

X-coor	Wdepth (m)	Wlevel (m)	Eq.conc (ppm)	Act.conc (ppm)	In.Blevel (m)	Mod.Blevel (m)	Sed.vol (m^3)
0	0.79	17.51	76.45	290	15.85	16.74	1409
100	1.12	17.51	1.62	290	15.40	16.40	1188
200	1.97	17.51	0	290	14.95	15.55	438
300	3.02	17.51	0	290	14.50	14.50	0
400	3.47	17.51	0	290	14.05	14.05	0
						Σ	**3035**

Two-year model

X-coor	Wdepth (m)	Wlevel (m)	Eq.conc (ppm)	Act.conc (ppm)	In.Blevel (m)	Mod.Blevel (m)	Sed.vol (m^3)
0	0.63	17.52	282.19	300	15.85	16.88	1630
100	0.98	17.51	8.25	300	15.40	16.53	1340
200	1.90	17.51	0	300	14.95	15.61	488
300	3.01	17.51	0	300	14.50	14.50	0
400	3.46	17.51	0	300	14.05	14.05	0

							Σ	3458

Three-year model

X-coor	Wdepth (m)	Wlevel (m)	Eq.conc (ppm)	Act.conc (ppm)	In.Blevel (m)	Mod.Blevel (m)	Sed.vol (m^3)
0	0.60	17.56	520	290	15.85	16.97	1748
100	0.96	17.55	17	290	15.40	16.59	1414
200	1.91	17.55	0	290	14.95	15.64	510
300	3.05	17.55	0	290	14.50	14.50	0
400	3.50	17.55	0	290	14.05	14.05	0
						Σ	**3672**

Table 6.2 shows that quickly after one year, large amount of the sediment has already trapped. It seems that after the second and the third year, the silt trap become much less effective and more sediment is transported to irrigation canal networks. It is also a bit unusual that in chainage 300 m and 400 m, are not filled in with the sediment. This is probably related to the model accuracy which is governed by the length step and time step of the model. It was set that the time step for calculation is two hours and the length step of 100 m. This is later will affect the Courant number which influence the stability and accuracy of the SETRIC computation.

According to the table of model output, after one year, there is 3035 m^3 sediment deposition of sediment in the silt trap. For two year and three year, the volume of deposition is 3457 m^3 and 3672 m^3 respectively. The above results are put into the graph which showed below.

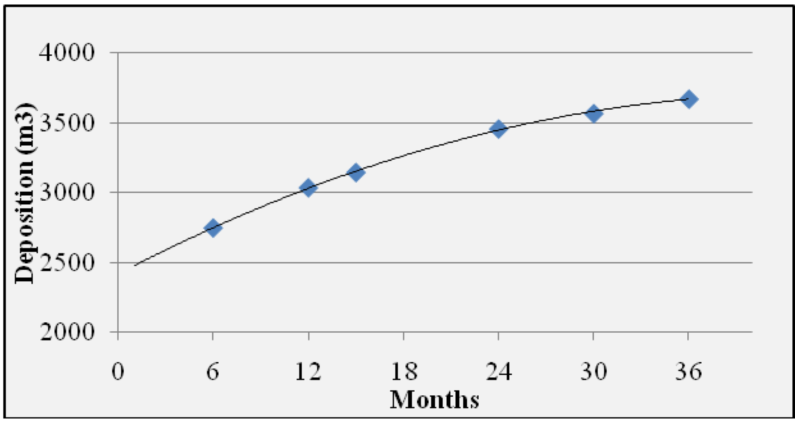

Figure 3 - Graph of sediment deposition in m^3 in time in the silt trap

According to the model result, the water level in the silt trap is +17.51 m above mean sea level. Meanwhile based on technical data, the maximum water level in the silt trap is +18.30 m above mean sea level. This means, roughly, the remaining height of 0.80 m is capacity of the silt trap to store the sediment. Hence the volume of the silt trap can be calculated, and result in 4,736 m^3

The model showed that within three years, amount of sediment deposition is 3,672 m^3 which means that the sediment trap capacity has been reduced into 1,064 m^3 or equal to 22%. Hence, if there is no maintenance activities planned, the settling basin capacity will be reduced and the bed level will rise. As the result, more and more sediment will transport to the irrigation canal and the field. So, it is proposed that the maintenance work should be carried out every three years at last with the volume of sediment to be removed of ± 3,600 m^3.

Removing sediment using heavy equipment is costly. Hence, the flushing method is seemed preferable to the management. The discharge needed to flush the silt trap back to Bekasi River is 20 - 50 m^3/s (Perum Jasa Tirta II, 2002) with duration of few days. However, this discharge is difficult to achieve, because the amount of water is also needed to be conveyed to drinking water treatment facilities in Jakarta. Since the minimum discharge needed to wash the sediment could not be met, the flushing will leaving some volume of the deposition at the silt trap. Therefore, in the end, using the heavy equipment is unavoidable.

The timing of the sediment removal in the silt trap is also essential. Delay in the maintenance works will affect the downstream irrigation canals because the sediment will be transported to the canals. As the results, more cost is needed for canals network maintenance.

The calculation of the silt trap capacity to store the sediment is rough. It is based upon assumption that the sediment can deposit in all along the silt trap. However, due to its position near the main intake, the sedimentation is hardly occurs at the beginning of the silt trap. The same situation takes place at the end part of the silt trap where the deposition seems will not as much as the middle part, because most of sediment will convey to the downstream canal. Realize these possibilities, the sediment removal work on the silt trap become more important.

b. Main canal, +3050 - +5050 m (BPa 2 - BPa 3)

Sediment deposition will directly affect the canal capacity in conveying water. To test the canal condition after certain period, canal capacity from result of three-year simulation is compared to the canal capacity at the design condition. Output file of the three-year simulation for sediment as follows:

The canal section between control structure BPa 2 and BPa 3 has total length of 2000 m. From the model, there is sedimentation with total deposition of 5362 m^3. It is assumed that this deposition distributed evenly in the canal, hence the bed level rise calculation is obtained that sediment height = 0.32 m

From this result, it can be concluded that if there is no regular maintenance, in term of sediment removal, implemented, there will be bed level rise of ± 30 cm. This will affect the main canal ability to convey the water to meet the secondary canal and the crop requirement. The current practice of the maintenance only implemented to cope with the weeds effect which scheduled every three months. Hence, it is suggested to carry out a maintenance plan which also deal with the sedimentation, especially in this section, where the model showed that significant amount of sediment took place.

This deposition is also influenced by the silt trap performance at the upstream part of the system, because when silt trap is filled up, sediment will be transported to the canal. Hence the comprehensive maintenance plan which covers the whole scheme as one system is needed.

CONCLUSIONS

After sediment transport simulations and the outputs analysis have been carried out, some conclusions given below.

- Bekasi Irrigation System has possibilities of considered high deposition of sediment due to its weir location in the downstream part of both Bekasi River and West Tarum Canal as supply canal.
- SETRIC model seems as promising tool to be used in assessing the irrigation system performance particularly for morphological changes in the canals network.
- Result of one and three years model produce similar pattern of SETRIC model output with the difference occurs in the quantitative of the sediment deposition and bed level changes.
- The model showed that bed level changing mainly takes place in the silt trap and the main canal at the section where the first secondary off takes located. The sediment also occurs in the downstream part of the main canals reaches or in other words where the discharge is already being taken to the secondary canals.
- SETRIC model result showed that, after three years the silt trap capacity will be reduced ± 80% of its maximum capacity. To avoid severe sedimentation take place in the canals network, it is suggested that the silt trap cleaning should be done at minimum once in three years with the dredging volume about 3,600 m^3.
- In the beginning of the study, SETRIC model is also expected to give suggestion on the operational side including tertiary off takes practices and water delivery schedule. Nevertheless, due to model limitation, data and time to do field measurement, it is can not completely accomplished. The research can only select the main canals to be modelled while the tertiary off takes operational does not affect much in the main canals operation. The reason is, although there is changing in water delivery of the tertiary off takes, the total discharge which conveyed in the main canals remain unaffected.
- SETRIC has given the prediction on canals bed modified due to sediment deposition. Its results need to be compared with the actual field condition. Therefore, it will give some ideas for program improvement in the future.
- Although the flushing back to the river could not totally wash away the sediment, it is recommended to study the impact of this "incomplete-flushing", upon the minimum interval of using heavy equipment in sediment removal. As the result, the total cost needed for maintenance can be optimized.

LIST OF SYMBOLS

A = area (m^2)
Q = discharge (m^3)
h = water depth (m)
V = mean velocity ($m^{1/2}$/s)
C = Chezy's coefficient (m/s^2)
R = hydraulic radius (m)
z = bottom level above datum (m)
g = gravity (m^2/s)
t = time (s)
Q_s = sediment discharge (m^3/s)

B = bottom width (m)
d_{50} = mean diameter of sediment (m)
p = porosity
n = Manning's roughness coefficient ($s/m^{1/3}$)
S_f = energy slope, due to uniform flow, it is equal with bed slope
c = suspended sediment concentration
u = water flow velocity in x (horizontal) direction (m/s)
w = water flow velocity in z (vertical) direction (m/s)
x = horizontal coordinates (m)
ε_x = sediment mixing coefficient in x direction (m^2/s)
ε_z = sediment mixing coefficient in z direction (m^2/s)
w_s = fall velocity (m/s)
i = $i\ \Delta x$
j = $j\ \Delta t$
z = bed level (m)
Δt = time step (s)
α = parameter used for stability and accuracy of the numerical system
N = exponent of velocity in the sediment transport equation $s = f(V^N)$
V = mean velocity (m/s)
Δt = time step / time interval (s)
Δx = length step / distance (m)
Fr = Froude number
C = total sediment concentration at distance x
C_e = total sediment concentration in equilibrium condition
C_0 = total sediment concentration at distance x=0
T_A = adaptation time (s)
L_A = adaptation length (m)

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