EFFECT OF WASTEWATER PUMPING OPERATION OF SEWER SYSTEM ON SEDIMENTATION AND OVERFLOWING OF WASTEWATER FROM SEWER PIPES

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ABSTRACT

Wastewater pumping operation has significant impact to flow in sewer pipes and sedimentation in sewer systems. Sedimentation in sewer systems reduces flow carrying capacity of sewer pipes and induces overflowing of wastewater from sewer pipes over land area. Frequency and magnitude of wastewater overflowing increase with the amount of sedimentation deposit. In calculation of flow in complicated sewer systems, normally exist in mega cities, traditional hand calculation seems to be impossible. With the use of powerful computers nowadays, mathematical and numerical models can compute and simulate flow hydraulic and characteristic including sedimentation in complicated sewer systems.

Many mathematical models for flow simulation in sewer systems are available. In this study the MOUSE ST model is used in computing and simulating flow and sedimentation during low flow in the wastewater collection system of the proposed Samut Prakarn Wastewater Project, in the eastern suburban of Bangkok. By the fact that the Samut Prakarn wastewater project has not yet been complete, the MOUSE ST model has been verified with the Pattaya urban catchment in the east of Thailand to ensure the capability of modeling sediment transport in the sewer system. In the verification, various methods of sediment deposit predictions were used such as velocity criteria, bed shear stress criteria, dimensionless bed shear stress criteria, sediment transport capacity criteria and the use of sediment transport equation together with sediment continuity equation. The selection of prediction method is based on the input data requirement and the accuracy of results required.

For Samut Prakarn province, by considering the self-cleansing criteria based on the critical velocity and the critical bed shear stress, the MOUSE ST is used to compute potential sedimentation locations in the sewer system. From the results of simulation, it was found that the self-cleansing criteria were not satisfied. The velocity in some branches was less than the critical flow velocity and the bed shear stress were less than the critical bed shear stress. The potential sedimentation in these branches was found to be nearly the same for both criteria. Various pumping operation

schemes were also studied in the sewer system. It was found that with a proper pumping operation scheme, there would be no sedimentation in the sewer system. In case of pumping operation failure, overflowing of wastewater from the sewer system will occur and result in unacceptable environmental impacts to the project area.

1. INTRODUCTION

Sediment deposits in sewers reduce the hydraulic capacity of sewer systems. This may cause flooding and consequently increase the volume and the frequency of the combined sewer overflows. The sediment deposits are removed on a regular basis at high maintenance cost. Knowledge in the amounts and locations of sediment deposits and their effects on sewer flow are necessary in order to take appropriate measures for an optimal operation and maintenance of the sewer system. Better planning of the maintenance scheme and of the design of the sewer system would be achieved with proper prediction of sediment discharge and deposition.

Due to complexity of sewer systems, mathematical models are often used to simulate flow and sediment transport. In this report, the computation of the effect from the sediment deposits on the hydraulic performance of the sewer system is carried out by the use of MOUSE ST model (DHI Water and Environment, 2001). The model is a deterministic sediment transport model for sewers, which is fully integrated with the hydrodynamic MOUSE model. Hence, the effects of reduction in flow capacity from both the reduction in flow area and the increased roughness from the sediment deposits are taken into account when the performance of sewers with sediment transport is evaluated. The MOUSE ST model has been successfully used to simulate the effect of sediment deposit in sewer systems in many countries. The results from the model prediction can be calibrated with the observed data. After calibration, the MOUSE ST model can be applied to predict future condition of sewer flow and sediment transport.

2. SEDIMENT DEPOSIT AND SELF-CLEANSING DESIGN CRITERIA

Many researches have been done dealing with sediment deposit in sewers. Some of them were on the prediction of where the deposition occurred (Mark et al, 1996). Other topics were on the behaviour of how sediment deposit occurred, and the predominant reason that causes sedimentation. The design method for self-cleansing sewers is another important thing in the sewer design. The results from the laboratory and field tests show that self-cleansing conditions cannot be adequately defined by a single value of minimum velocity or shear stress (May et al, 1996). However, at present the practical design of self-cleansing sewers is still based on two design criteria, the velocity and bed shear stress criteria. In Thailand, the velocity criteria are widely used for self-cleansing sewers in which minimum average velocity (half-full flow) of 0.9 m/s must be maintained all the time. For the Samut

Prakarn wastewater management project, according to the project design criteria the minimum velocity is slightly different from the normal standard, the minimum velocity is set to 1 m/s for pipe flowing full or 0.6 m/s for 15% flowing full.

3. THE SEDIMENT TRANSPORT MODEL

The complicated effects of the sediment deposits on the hydraulic performance of the sewer system in this study have been investigated by using the MOUSE ST model Version 2001. MOUSE ST is an advance deterministic sediment transport model for sewers, which can compute both static bed and movable bed. MOUSE ST computes both hydrodynamics using fully St Venant equation flow equations and sediment transport with 4 selectable sediment transport formulae at the same time (DHI Water & Environment**,** 2001). In this paper, the design of Samut Prakarn Wastewater Management Project is rechecked for the self-cleansing ability to determine the sediment deposit areas and effects of pumping stations on hydraulics and sediment transport characteristics of the sewer system.

4. APPLICATION OF MOUSE ST MODEL

Due to local resident protest and government administration problems of the actual sewer system area, the Samut Prakarn Wastewater Management Project has been almost completed but still suspended. No data is available for the calibration and verification of the MOUSE ST model. Instead, two pilot projects, which applied the MOUSE ST model, were then used in checking the capability of MOUSE ST for modeling sediment transport in sewer systems.

4.1 The Ljubljana sewer system

Mark et al. (1996) used the MOUSE model package to develop a master plan for the city of Ljubljana-capital of Slovenia, Eastern Europe. One of the objectives of the master plan is to evaluate the effects from combined sewer overflows on the water quality of the Ljubljana River and subsequently to reduce the load of pollutants from the sewer system to the river. The Ljubljana catchment is 4,000 ha and has a daily load around 240,000 person equivalents including industrial wastewater. The purpose of the study was to predict the location of sediment deposits and to evaluate the effect on the changes in sedimentation pattern from implementation of the master plan. For Ljubljana project, MOUSE ST was used in the conjunction with the hydrodynamic MOUSE model. The hydrodynamic model has been calibrated and verified against water levels and discharges measured at 17 locations in the sewer systems. Also another field survey was carried out for selected overflow structures to inspect the sediment and to verify the model simulation result. The results of the study showed that MOUSE ST could be used to predict closely the locations where the sediment deposits occur. Further, the model has been used to evaluate the effect of cleansing of the sewer system, i.e. the removal of the sediment deposits, on the combined sewer overflows.

4.2 The Pattaya sewer system

Pattaya, ranked the second best travelling spot in Thailand, has the feature as coastal lowland area, beach and islets. Pattaya beach, especially, is the famous attractive beach in the country. Being influenced by monsoon in summer and winter, the weather is warm throughout the year. Pattaya is located about 150 km to the Southeast of Bangkok. The total area of the city is 208.1 km^2, including land, water and islands. It consists of Na Klua District (Coral Island, Krok Island, and Sak Island), Nong Prue District, part of Huai Yai District and Nong Pa Lai District and a water area of 154.66 km^2. It has 15 km long beach. The Pattaya catchment is divided into two main zones: Na Klua Zone and Pattaya Zone, Na Klua Zone has about 46 sub-catchments, and Pattaya Zone has 44 sub-catchments. In those sub-catchments, there are some catchments with a high density of tourism with different water consumption standards.

Due to high pollutant loads from the residences, the Public Work Department has improved the drainage system. They managed to install large pipes at Kasemsuwan road to solve flood problems in Central and Southern Pattaya. The new wastewater treatment plant has been built and was in operation since November 2000. The existing sewer system in Pattaya is a combined sewer system and serves 80% of the city area. The closed sewers are designed for a return period for 5 years and 10 years for open channels. The system has two pumping stations at the end of the pipe system and seven overflow weirs discharging a mixture of sewage and rainwater directly onto the beach. The Pattaya beach is seriously polluted, primarily due to domestic wastewater discharging from illegal settlements on the shoreline, hotels and restaurants together with the combined sewer overflow (CSO) during heavy rain.

4.2.1 *Principles for modelling and locations of sediment deposits*

The modelling of sediment transport in sewer systems must be run together with the hydrodynamic model. A general problem of sediment transport modelling is that often only few field data are available. It is difficult and expensive to collect data for calibration of the model. Sediment transport is a highly non-linear function of the hydraulic conditions in the sewers. So the hydrodynamic model must be well configured and calibrated. In this study, sediment transport modelling has been carried out with limited field data of sediment transport. The prediction the potential sediment deposit area is based on the sedimentation/erosion pattern predicts from the use of the sediment transport model. With the use of the MOUSE ST model, the output can be shown in the sewer system plan view for the velocities and bed shear stresses in all sewer lines. The sewer pipes that do not satisfied the self-cleansing criteria have high potential for sediment deposition.

For the Pattaya sewer system, three locations of the project area are selected for the calibration of the MOUSE hydrodynamics model**.** After the calibration of the hydrological and hydrodynamic models, the Engelund and Hansen sediment transport model, MOUSE ST, is then calculated together with the calibrated hydrological and hydrodynamic parts to simulate the potential sediment deposit locations for the specified scenarios. After the simulation of various flow scenarios, the results of the model were compared with the field conditions.

4.2.1.1 *Prediction of locations of sediment deposit in the Pattaya sewer system*

The potential sediment deposit locations can be predicted by the use of MOUSE ST in many ways. The simplest way is the use of minimum flow velocity during 24 hours of diurnal dry weather flow. The velocity criteria take no account of the sediment or pipe characteristics. A more accurate way of predicting the sediment deposit location is the use of bed shear stress or dimensionless bed shear stress. In this method, some of the pipes and sediment characteristic is used to calculate the bed shear stress. Another method is the use of sediment transport capacity in predicting potential sediment deposit locations. The method considers potential of pipe to transport the sediment without the guarantee of sediment available. The most reliable method of predicting sediment deposit is the use of sediment continuity equation. This method requires a lot of accurate input data. The selection of the methods to predict potential sediment deposit locations depends on the available data and the significance of deposition. The more the accurate results, the more reliable data and simulation time is required.

Method of critical velocity, bed shear stress and dimensionless bed shear stress

The method compares the computed velocity, bed shear stress and dimensionless bed shear stress from the model with the critical values. For deposition, the critical velocity, bed shear stress and dimensionless bed shear stress are 0.6 m/s, 2 N/m^2 and 0.055 respectively. Deposition will occur when the velocity is less than 0.6 m/s, bed shear stress is less than 2 N/m^2 or when the dimensionless bed shear stress is less than 0.0055.

Method of sediment transport capacity

The method consists of running the hydrodynamic model and a sediment transport model with a fixed sediment depth in the individual pipes but the bed level is not updated during the simulation. After the simulation is run the maximum sediment transport is plotted on a horizontal plot, with an indication of the flow direction. The sediment is likely to deposit at the locations where the sediment transport capacity is decreasing in the flow direction. This simulation can be run with and without sediment deposits, allowing the comparison of the water levels in both cases (an indirect way of determining the flow capacity of the sewer) and thus giving an estimation of possible combined sewer overflows (CSO).

The advantage of this method is that the computation time and the data requirement is very small. However, the method does not consider the factors such as sediment availability and the routing time of the sediment, i.e. the maximum sediment transport capacity may occur at a time when no sediment exists in the real situation.

Method of continuity equation and sediment trasport equation

The method uses a hydrodynamic model and a sediment transport model in parallel in computing the new bed level. The sediment model gives feedback to the hydraulic model in terms of flow areas and resistance numbers, i.e. the Manning number. This new information then constitutes the basis for the calculation of water levels, discharge, velocity, etc. The initial depths of the sediment deposits are specified for the individual pipes and the numerical computation is carried out to determine the locations of sediment deposits.

The advantage of this method is that it gives directly the locations where sedimentation occurs and it takes factors as sediment availability and the routing time of the sediment into account. However, the method requires an estimate of the sediment deposition depth in all pipes in the sewer system and the input of sediments to the system. The potential accummulated erosion/deposition is calculated based on the sediment transport continuity equation for the sediment transport capacity for each time step during the simulation.

4.2.1.2 *Selection of prediction method*

Five different parameters have been used and compared to each other by MOUSE ST. The velocity criterion is the easiest way to locate the deposited area. It uses very little information on the flow parameters without using the information of the pipe or sediment. The sediment transport capacity, bed shear stress and dimensionless bed shear stress method are also fast and data requirement is small. However the methods do not take into account the factors of sediment availability and the routing or traveling time of the sediment. On the other hands, the method of continuity equation for the bed sediment gives the sediment deposit locations taking into account of sediment availability and routing time. The continuity of sediment method requires more data of the existing sediment deposition depths in pipes before calculation as well as the inflow data of sediment, which is very difficult to measure in the real situation.

The selection of the method to predict the potential sediment deposit locations depends on the available data and the accuracy of the result. For preliminary information the velocity criteria seems to be acceptable without the use of sediment transport model. For a more accurate prediction, the use of sediment transport capacity, bed shear stress and dimensionless bed shear stress are recommended by using simple sediment transport model. For crucial calculation, the use of sediment continuity equation method will give the most reliable result on the sediment deposit area.

5. THE SAMUT PRAKARN WASTEWATER MANAGEMENT PROJECT

In this study, the Samut Prakarn Wastewater Management Project, figure 1, the biggest wastewater management project in Thailand that has a project area of 127 km^2 with 850 nodes or manholes and 125 km of pipes ranging from 300 mm to 3,000 mm will be considered. The self-cleansing ability is analyzed to determine the sediment deposit locations as well as to simulate pumping effects of flow in sewers. The sewer system consists of eight pumping stations with a total capacity of 23.5 m^3/s. Six of them are used as lift stations, one for pumping water across under the Chao Phraya river from west side to east side. The last one is for pumping all wastewater to the wastewater treatment plant. Montgomery Watson Asia together with SEATEC has designed the project in 1995. Also the hydraulic capability to convey the designed wastewater flow and the sediment transport capability of the wastewater collecting system in a low flow condition (without rainfall) must be ensured. The system has a constant design dry weather flow of totally 525,000 m^3/d (NVPSKG and North West Water International, 1998). At present, the project is under the construction period and due to some land acquisition problems, the completion of the Samut Prakarn project was suspended.

The Samut Prakarn sewer network data is input into the MOUSE ST model with the design parameters as it is in the earlier design study. After input all the data into the MOUSE ST model, the model is run for one day with design dry weather flow. All the pipes are designed corresponding to the year 2015 sediment load and flow distribution. Design peak flow factors for dry weather flow range from 5.0 for small flows of 1000 m^3/d. to 2.0 for large flow of 200,000 m^3/d. The Samut Prakarn sewer system is run with Engelund and Hansen total load formula for four cases of different sand diameters ranging from 0.1, 0.5, 1.0 and 2.0 mm. All of the pumping stations are considered to run with full capacity according to the rating curves. Also the cases of pump failure have been simulated in this study. The sewer system is subjected to cover the same design dry weather flow for the year 2015 with no pumping stations.

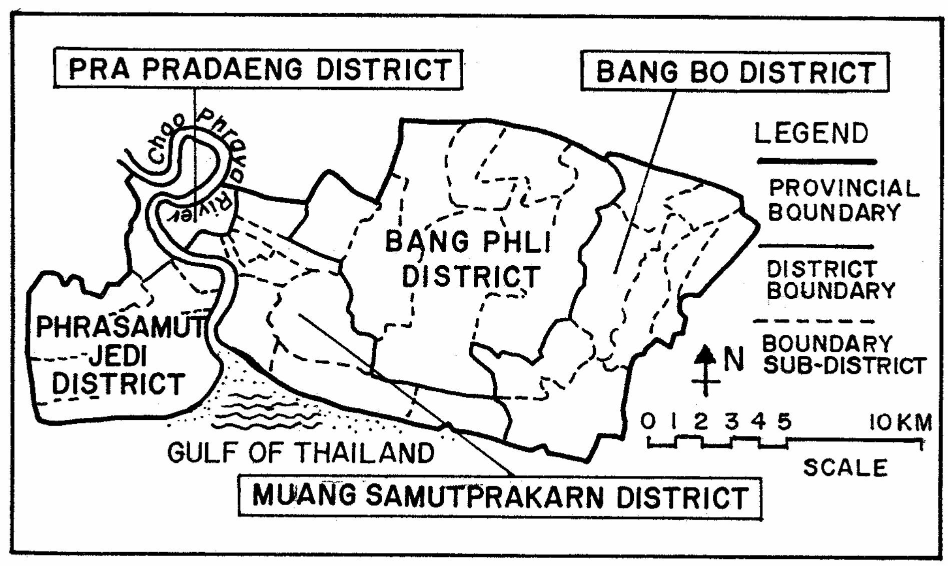

Figure 1: Municipals & Sanitary districts in Samut Prakarn province

6. RESULTS AND DISCUSSIONS

All the pipes are designed corresponding to the flow distribution in 2015. The design peak flow factors for dry weather flow range from 5.0 for flow of 1000 m^3/d. to 2.0 for flow of 200,000 m^3/d. The most two important simulation results related to the design of self-cleansing sewers and sediment deposit are the maximum velocity and the maximum dimensionless bed shear stress. All the simulations were run for a period of one day. If the computed maximum flow velocity is greater than 0.6 m/s or the computed dimensionless bed shear stress is greater than 0.055, it could imply that at least there will be a period in a day that the sediment can be flushed out. The simulation results from the four cases of sand of different diameters give the same velocity in pipes. This means that the velocity computed from the model is not related to the sediment size. If the critical velocity method is used as the design criteria, the method would yield the same design pipe slope regardless of sediment diameters. The procedure of determining self-cleansing from velocity seems to give unreasonable results. The plot of maximum velocities in all pipes is shown in figure 2. In the figure, a thicker line shows the pipes with a maximum velocity less than or equal to 0.6 m/s.

For the maximum dimensionless bed shear stress, more reasonable results are obtained. For the smallest sand size diameter of 0.1 mm, the critical pipes in which the maximum dimensionless shear stress is less than 0.055 are those small pipes in the upstream area as shown by circular dotted lines in figure 3. The number of critical pipes increases when the diameter of the sand sediment increases. The thick black lines as shown in figure 3 are the additional pipes from the circular dotted lines when the sand diameter is increased from 0.1 mm. to 0.5 mm. The dashed lines illustrate the additional pipes for sand of diameter 1.0 mm. The entire pipe system is subject to deposit when the sand diameter increases to 2.0 mm.

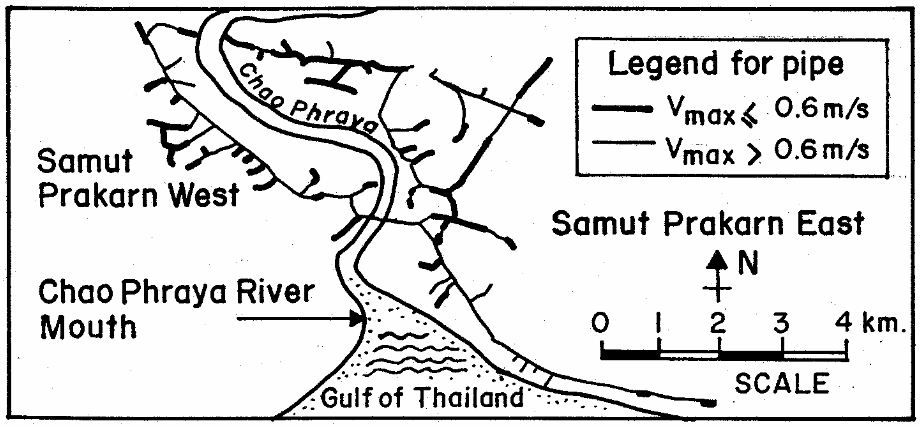

Figure 2: Horizontal plot of maximum velocity in the project area

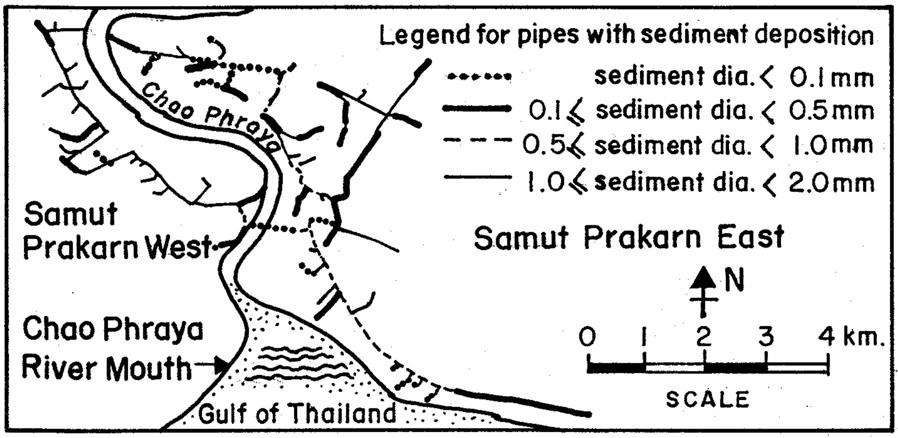

Figure 3: Horizontal plot of maximum dimensionless bed shear stress in the project area

The results from the model both from velocity and dimensionless bed shear stress criteria show that the most critical pipe lines in the Samut Prakarn sewer system are the circular dotted lines and the thick black lines indicated in figure 3. For this area the daily maximum velocity are less than 0.6 m/s. Also the maximum dimensionless bed shear stress for sand of diameter less than 0.5 mm. is less than the critical value of 0.055

For the effect of pumping in the Samut Prakarn sewer system, the only way for water both from rainwater or waster water from houses or factories to go through the system is by pumping. The design of pumping station in this situation is very important. In this study, a model set up is considered with only one pumping station to pump wastewater across the Chao Phraya River under the riverbed from the west bank to the east bank. The same input data and parameter were used are as in the full system. The purpose is to see the effect of pumping stations in this system. From the results of the simulation, the water level in all branches in the eastern area in the case of having only one pumping station is more than 0.6 m. MSL. This water level is nearly reaching the average ground level of the city while in the full system with eight pumps the water levels range from –5.0 to –10.0 m. MSL. On the other hand with full pumping scheme, the model results indicate that no flooding occurred. If all pumping stop, the wastewater in the sewer pipes will overflow and flood the city.

7. CONCLUSION

The design of sewer system must be ensured to have the self-cleansing against deposition in the sewer lines. At present the advance and up-to-date methodology for designing of self-cleansing considered more factors such as sediment concentration. Practical design recommended in the design book of many countries still based on the only one-parameter criteria, the minimum velocity or the minimum bed shear stress. In Thailand the design criteria are based on the minimum average velocity of 0.9 m/s for half full flow, which is easier in the design.

In this paper for the Samut Prakarn sewer system, two design criteria are compared by the use of mathematical model applied to the real sewer system namely, the Samut Prakarn sewer system. From the theoretical point of view, the velocity criteria method requires more design slope for a small pipe diameter. Velocity criteria method does not consider the effects of sediment particle sizes. The bed shear stress criteria, which are related to pipe perimeter and particle grain size, give a more reasonable result in designing the self-cleansing sewers. For the bed shear stress criteria, we can conclude that: if $\theta_c > \theta$ deposition will occur and if $\theta_c < \theta$ the sediment deposition can be determined by the sediment transport equation. Sediment deposit occurs only if the sediment inflow is more than the sediment outflow.

The results from MOUSE ST both in terms of velocity and dimensionless bed shear stress show that the Samut Prakarn sewer system is not 100% self-cleansing during the dry periods, which are considered to be the most critical case. From the velocity point of view, nearly all the small sewer branches have not enough slope for self-cleansing. Furthermore some main pipes also have the same problems as shown in figure 2 during dry periods. Compared to the design based on the dimensionless bed shear stress, even for the dry period with small amount of discharge, nearly all flows in sewer pipes satisfy self-cleansing condition for sand of diameter less than 0.1 mm. The number of self-cleansing pipes reduces as the sand particle size increase. When the sand diameter is 2 mm, no pipes satisfy the self-cleansing criteria. It can be also seen from figure 2 and figure 3 that the velocity criteria give the nearly same result as the dimensionless bed shear stress of sand of diameter 0.5 mm.

When the design of the sewer system does not fully satisfy 100% free of deposition, a good operation and maintenance of the system may help to relieve the problem. The comprehensive criteria of the sewer design should consider many aspects such as, self-cleansing, drainage purpose, economic etc. However due to the complexity of the problem prevent us to include all of these aspects in the design. The sewer system in this study has been designed satisfactorily to the self-cleansing condition. The system is quite sensitive to the change of sand particle size as show in figure 3, especially on the pipe slope. One example of maintenance work recommended by the model is that from the bed shear stress criteria each pipe has one critical sand diameter from the model. It is recommended to protect sediment of size larger or equal to the critical size to enter into the sewer pipes.

Another point of the operation of this sewer system is that there are many pumping stations located in the project area. With the pumping stations, pipe discharge, which related to velocity and bed shear stress, can be adjusted manually by the system operation. In case of heavy deposition, flushing of the sediment deposit material can be done.

From the above mentioned results of the model study, some specific conclusions are mentioned as follows:

1. Under the full system operation, there is no flooding at any nodes and branched.
2. The velocity in some branches of the Samut Prakarn sewer system is less than 0.6 m/s. throughout the time period of simulation. This means some deposition of sediment will occur.
3. The lift (pump) stations within the network are necessary in this system. If the lift stations are not operated, flooding due to overflow of wastewater will occur in the east and west bank areas.
4. It is observed that the pump operation curve has a lot of effect on the system operation. Different pump operation curves give different flow conditions in pipes and can cause rapid changes in pumping discharges. Refinement of pump operation rule curve is required for a smooth change in pumping discharge and gradually varied flow in the system.
5. It is found that the pipe flow is mostly half full, which indicates to a good design. However, changing of some parameters such as pipe diameters or pipe roughness coefficient has a lot of effect to flow and velocity and hence sediment transport in the pipes.
6. A careful model calibration is needed using the data of flow and sediment transport collected after the sewer system under operation.

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