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INLET AND SEWER TRAPS FOR SEDIMENT CONTROL IN STORMWATER DRAINAGE - A MALAYSIAN CASE STUDY

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ABSTRACT

The city of Alor Setar in Kedah, is an important developing centre of business and communications for the Northwest of Malaysia. However, the capacities of the existing storm drains in Alor Setar are severely restricted as a result of sediment deposits washed-in during high intensity rainfall events. These deposits result in stagnant, polluted areas of water within the catchment and a loss of hydraulic capacity needed to deal with large storms. Methods of sediment deposition prediction have been applied to UK catchments with limited degrees of success. The application of these methods has been used to propose an improved sediment management strategy for Alor Setar. The methods involve the development of a simplified hydraulic model of the test catchment and the prediction of areas within the system where deposits are most likely to occur. Using this formation, options for invert trap placement can be developed in order to determine their most effective locations. Further analyses are also proposed in order to determine the fill rates of these traps throughout an average year. A proactive maintenance plan can therefore be developed in preference to the reactive maintenance methods currently employed. This planned programme of maintenance should ensure that best use of traps is made at all times in order to protect the system from flooding and pollution problems.

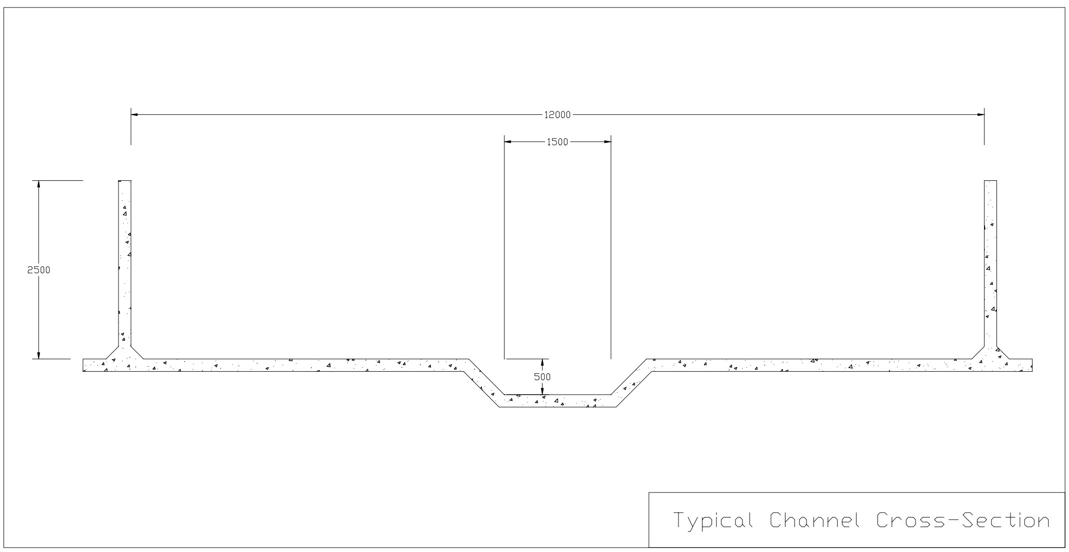
KEYWORDS

Deposition; invert traps; sediment management strategies; urban drainage

INTRODUCTION

Industrial and commercial development relies on adequate infrastructure. The provision of civil infrastructure is of greater importance in developing countries, expanding rapidly. This is the situation for the city of Alor Setar in the state of Kedah, Malaysia. The city has recently seen extensive economic development and has been designated to be a centre of communications for the Northwest of Malaysia. As a consequence of the rainfall characteristics of the area (approx. 2500 mm per annum), urban drainage is a key aspect in the continued economic development of this expanding city. The Raja drainage catchment is part of the Alor Setar Town Drainage scheme. The scheme comprises three catchment basins (Raja, Langgar & Putera) and was proposed as part of a flood alleviation programme for the region. The Raja basin is the largest in the area and is also the most prone to problems of flooding. Flows from the Raja basin are drained by gravity to a pump station before being discharged via pumping mains to the Sungai Kedah waterway. The main lengths of the drainage system take the form of trapezoidal/rectangular, open channel sections (Figure 1). The sections are lined in concrete, vary in width from 4 to 16m and have been designed to a minimum velocity criterion for the purposes of sediment cleansing. However, resulting from the relatively flat topography of the area, during the operation of the scheme, the channels have become up to 50% filled with sediment. This clearly restricts the hydraulic capacity of the channels and also exacerbates existing problems of stagnant water/effluent in the area. The proposed solution involves holistic analyses, the installation of sediment control devices, and a proactive maintenance programme. As part of the first stage in the development of a sediment control strategy, a method was developed and tested for the prediction of sediment deposition.

Figure 1 - Typical Rectangular Cross Section

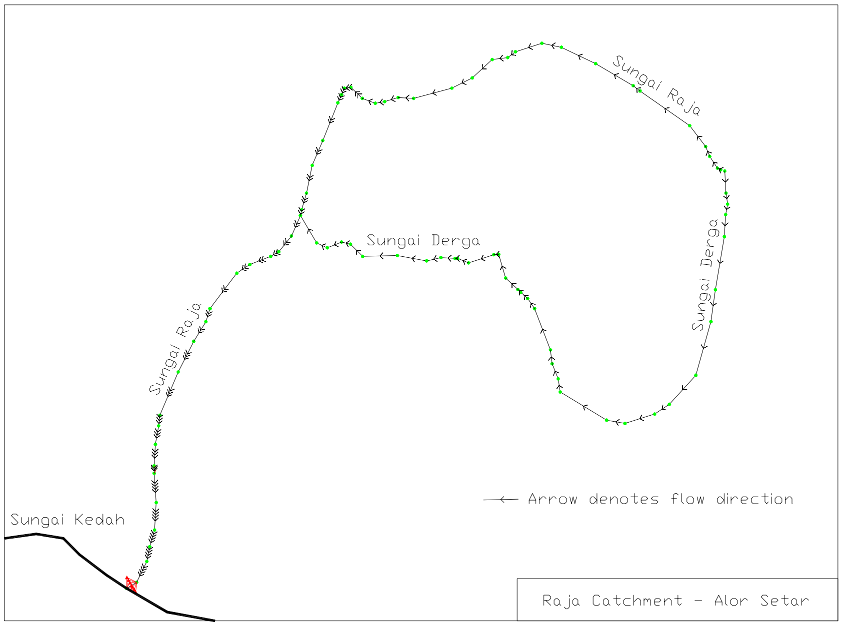


It has been suggested that the new generation of commercial sewer flow quality models may be used to determine sediment deposition (e.g. MOUSETRAP; Mark et al., 1998). However, these models have been shown to be very sensitive to small changes in critical data such as particle characteristics and bed strength (Gent et al., 1996). Methods based on mapping boundary shear stresses have been used in the past to predict areas of potential deposition (Pisano et al., 1979; Gent and Orman, 1991; Mark et al., 1998). The various applications of the methods have varied slightly in technique, but all have essentially involved the prediction of flow velocities and resulting boundary shear stresses. The method due to Gent and Orman has been tested with reasonable success in a catchment in Dundee, and is therefore believed to be of reasonably sound theoretical foundation.

METHODS

The hydraulics of the Raja drainage scheme were represented using the HYDROWORKS full solution model (see Figure 2).

Figure 2 - Schematic of the Raja Catchment Drainage System



Although the town of Alor Setar has no established sewerage system, foul inputs to the Raja drainage system are common-place as a result of the poorly maintained septic tank facilities (seepage) and also the practice of tipping both solid and liquid refuse into the drainage channels. This adds to water quality problems and channel blockage, particularly at channel bridge crossings and culverts. The dry weather component of the system was therefore represented by the use of a steady 'sewer infiltration' flow of approximately one sixth of the capacity of the dry weather flow channel. Flow control at the base of the catchment is provided by gates at the intersection between the Sungai Raja and Sungai Kedah, and by the use of seven pumps of varying capacity.

The Soil Conservation Service (SCS) runoff model was utilised, as a rapid runoff model (commonly used in the UK) was deemed inappropriate due to the semi-rural nature of the catchment. Rainfall inputs for the model were determined using the HYDROWORKS Hong Kong rainfall generator, with adjustments made for the low returns periods used (<6 months). The resulting flows were used as the basis for determining the erosional characteristics of the system, and hence predict likely areas of deposition.

Within the UK, an unpublished method proposed by Gent and Orman (1991) has been used with limited success in the prediction of sediment locations. Although developed for use in UK closed, circular conduits, the basic approach can be adapted to suit any drainage system.

The basic procedure involves the analysis of conduits under the following conditions:

- Peak dry weather flows

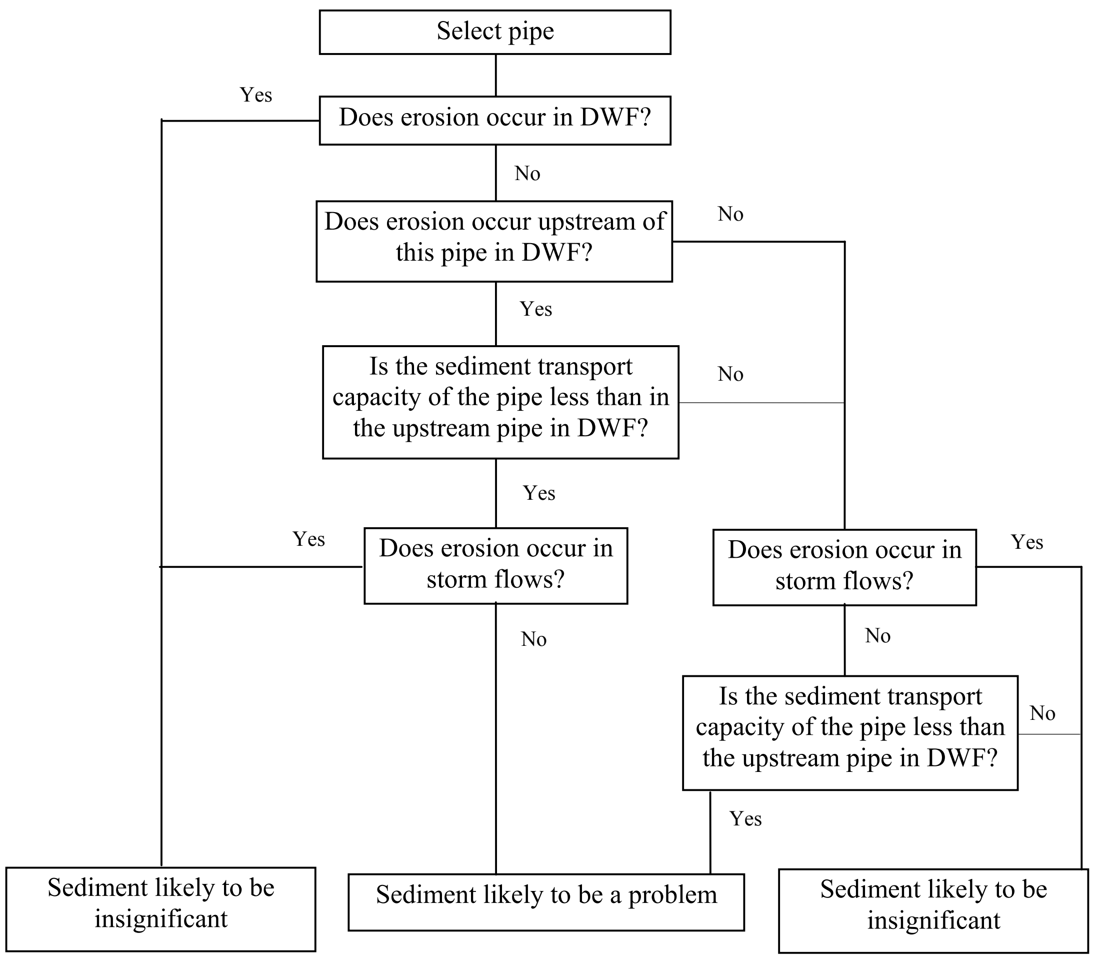
The erosion condition for discrete sediment particles is determined and compared with the observed conditions. In conduits where erosion is not predicted, deposition is only possible if there is a reduction (from upstream) in sediment transport capacity. Where both these criteria are met, the procedure is continued form storm flows.

- Peak storm flows from 2 storms of known return period

It is assumed at this stage that some degree of ageing and shear strength development has taken place in the bed. Therefore, an analysis of discrete particle erosion is not used. As an alternative a critical bed shear stress criterion is used for both storm events. The sediment transport capacity is then calculated for the conduits where erosion is not predicted, and compared with upstream values.

From these basic principles an ordered procedure was developed, allowing a systematic check of any drainage catchment to be made.

Figure 2 - Flow diagram of Gent & Orman Procedure to Locate Sediments



Procedure Alterations

A modified version of this procedure has recently been applied to an urban catchment in Dundee, and has been seen to produce good indicative results. However, as a result of the very different nature of the Dundee and Malaysian catchments, the procedure given above (Figure 2) was modified further for application to the Raja drainage system:

- Although the Raja drainage system was designed for surface water drainage only, a substantial number of foul connections have been made to the system. For this reason, analysis was carried out for the dry weather channels of the system. Erosion was determined using Ackers-White (1973) theory, and sediment transport capacity calculated using Ab Ghani's (1993) relationship.
- Alterations to the form of sediment transport relationship utilised were required in order to account for the presence / absence of sediment bed, and section characteristics.
- The original procedure assumes that all sediment originates from in-pipe deposits. Therefore deposition can only occur given an eroding, upstream source. However, as the sediments washed into the Raja system are believed to originate from surface sources, this simplification would have ignored the largest source of sediments for the Raja catchment. Therefore, for storm flows, erosion was always assumed to take place at upstream sections.
- Erosion during storm flows is assessed using a minimum shear stress criterion. The values of shear stress used, relate to the type of material considered, and the degree of ageing experienced by the material prior to the onset of rainfall. The critical stresses used in the original procedure were 9 N/m^2 for lightly consolidated sediment, and 2.5 N/m^2 for freshly deposited sediment. Investigations carried out into critical shear stresses for consolidated sediment (Nalluri, 1991), suggest that the figure of 9 N/m^2 should be reduced for 'typical' UK sediment. Hence these values were significantly reduced for use in the Raja study, predominantly as a result of the Alor Setar sediments being less organic than UK sewer sediments. Values of 4.5 and 1.5 N/m^2 were selected using data given for permissible unit tractive force based on void ratio and soil type (Graf, 1984).

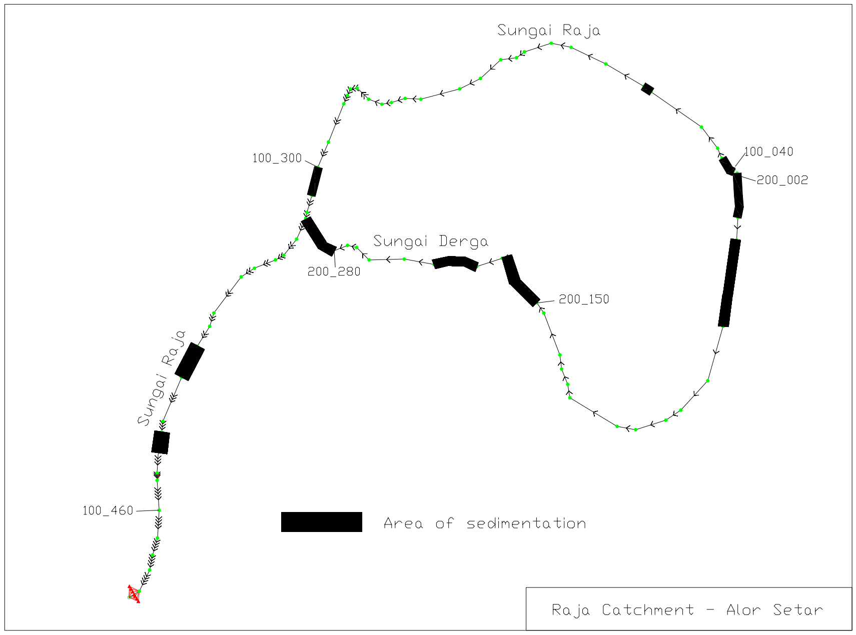
RESULTS

The modified procedure was carried out using the HYDROWORKS Raja Catchment model. The areas highlighted by the analysis as being prone to sedimentation can be seen in Figure 2. These areas were generally characterised by slack or adverse gradients, or in certain cases, affected by the interaction of the merging Sungai Raja and Sungai Derga (100_300 and 200_280 respectively).

The most extensive areas of deposition were predicted at the head of the Sungai Derga, where much of the solids are initially washed-in. A less extensive area of deposition was also predicted for the head of the Sungai Raja. Given the relatively approximate nature of this initial model, it is interesting to note that deposition is predicted in a small culvert located near the head of the Sungai Raja waterway. This shows that relatively small structures can be accounted for in the analysis.

The operation of the pumps at the base of the catchment was observed to be crucial in determining boundary shear stresses for over 500 metres upstream, however, deposits were still predicted in the area of pumping influence.

Figure 3 - Areas of predicted deposition



DISCUSSION

Traditional verification of the sedimentation prediction methods is very difficult to apply in this particular case, as the sedimentation is now so severe that it affects the entire length of the drainage system. At present, it can only be stated that results from the analysis do correspond to the areas suffering from the highest degree of deposition. Indeed measurements of sediment depths taken at key points during a significant rainfall event have suggested that deposition still took place in some of the areas highlighted by the above procedure. Minor deposition was observed at the head of the Raja waterways (100_040), with greater deposition observed near the head of the Sungai Derga (200_002). During the rainfall event, erosion was observed at all other measurement points, including one area of predicted sediment deposition. However, the recorded event was more severe and prolonged than those used in the sediment prediction analysis.

Although no formal verification of the analysis has been carried out, examination of the results show only few deviations from expected figures. For example, the lower sections of the Sungai Raja (downstream of the Sungai Derga interception) were expected to suffer much more severely from depositional problems than the results would suggest. This area is characterised by slack gradients (average 1:2000), with several of the sections lying at adverse gradients. It is possible that discrepancies between predicted and observed data may exist in this area as a result of the effects of the pumped outfall. Within the model widespread deposition was not predicted, but shear stresses were seen to vary greatly from channel length to channel length. This is believed to be a symptom of pump operation and could be refined with further work. The effects of the pumps during peak flows clearly assist the transport of sediment by accelerating flows towards the outfall. However, during times when the pumps have become inactive sediment will begin to settle in lower parts of the system, prior to the re-activation of the pumps. Studies have shown that significantly higher values of shear stress are required to erode particles of sediment than are required to keep them in suspension (Berlamont and Torfs, 1996), therefore the times when pumps are inactive must be minimised. By combining hydraulic and sedimentation, models pump operation can be optimised.

Proposed Sediment Control

The knowledge of locations of these initial deposits allows a reasoned approach to invert trap placement to be adopted. It is therefore proposed that invert traps be placed at the following locations (

Figure **3**):

- inlets to the main system (nodes 100_040 and 200_020);
- upstream of the series of sharp bends at the mid point of the Sungai Derga (node 200_150);
- upstream of the junction between the Sungai Raja and Sungai Derga (nodes 100_300 and 200_280);
- upstream of the flow control pumps, in order to protect the pumping station from sediment impact damage during very high flows (100_460).

As an alternative to placing an additional trap on the lower reaches of the Sungai Raja it is proposed that pump operation be optimised to prevent the deposits in this location. Any sediments washed-in would therefore be carried downstream to the trap protecting the pumps.

Trap Sizing and Maintenance

As a sediment trap fills, its trapping efficiency is slowly depleted. Studies in the UK have shown that traps generally fill at close to their maximum efficiency until approximately 80% filled with sediment (Dartus et al., 1990). Consequently, in order to achieve the maximum potential of a trapping strategy, trap maintenance should be planned to avoid a loss of trapping efficiency. Work carried out in Dundee has suggested that fill rates for these traps can be accurately estimated using time series rainfall (Fraser et al., 1998). Using this approach the volumes of sediment deposited in any given trap can be used to determine a trap size and maintenance period.

CONCLUSIONS

Application of a modified sewer deposition model has been shown to produce results which without further verification can only be said to be reasonable. With further refinement and calibration it is believed that a combined hydraulic/sedimentation model can prove to be a useful tool in the management of both urban and rural drainage schemes. The Alor Setar drainage scheme offers the opportunity to apply what has been generally UK experience on a much wider scale, thus allowing the validity of the proposed approach to be tested at new limits in a relatively simple drainage system.

By continuing the work carried out in Dundee on trap fill rate it is envisaged that a cost effective maintenance plan can be developed for the Raja catchment. Immediate improvements to the system can be implemented by the optimisation of pump operation to minimise sedimentation. Future implications of this work will allow the existing pollution problems in this area to be tackled by the reduction of areas of stagnant water bodies and decomposing sediment masses. It has also been proposed that given further chemical analysis of the existing sediments, weighting factors can be applied to the finer particles transported, in order to give a measure of their pollutant impact.

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