A Temporal Change Study of the Muda River System over 22 Years


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ABSTRACT

The Muda River has been dramatically affected by unsustainable human activities that sacrificed environmental values for national development. The removal of the forest canopy causes a decrease in the interception and transpiration in a basin. The decrease in transpiration leads to an increase in the amount of water stored in the soil. These changes can increase the soil’s moisture content, allowing more water to be available to drain into channels. Tree clearing can also cause increased erosion at logged sites and a subsequent increase in sediment yield. In this study, an investigation of the spatial and temporal changes to the environment imposed by new land usages on a long timescale (over 22 years) was carried out in the Muda River area. Detecting the changes in land usage will help predict both the consequent changes to the Muda’s River behavior and flood risks. In addition, computer modeling (InfoWorks RS) was used to help determine the long-term behavior of the Muda River and its flooding behavior.

Keywords: Land use, Flooding, Hydrodynamic modeling, floodplain, flood map

1.0 Introduction

Natural forces do not solely cause floods in Malaysia today; rather, floods are a byproduct of the interaction between natural events and human activities. Continuous changes in land usage and climate affect the geomorphology of river systems (e.g., Toy et al., 2002 and Houben et al., 2006). Many anthropogenic land usage patterns (e.g., agriculture, industrialization, commercial, residential) are concentrated along rivers and in the vicinity of floodplains and submergible areas throughout Malaysia. These activities are continuously subjected to the catastrophes of flooding. In the light of Malaysia’s vision to be an industrial nation by 2020, more and more floodplain areas are expected to be developed, thereby exposing even more people and property to the risk of flooding. Flooding occurs when the river cannot cope with extra water coming from the river catchment area, which causes the level of the water in the river to rise and a flood to occur (Hyndman and Hyndman, 2006). Significant destruction and losses of property, life and money are with the results of catastrophic floods. These hazards continue to be a threat in Malaysia, especially since people choose to occupy floodplains, ignore the
dangers of such hazard zones, mismanage flood hazards, over-develop land and deplete natural resources at rates that the natural system can neither cope with nor adapt to (Abdullah, 1999).

Stream channels are complex systems in space and time (Lane and Richards, 1997), and a single change often triggers another, causing multiple effects from a single cause (Schumm, 1974). Often, stream channels respond negatively and impact the riparian habitat and water quality. The literature on this topic indicates that a variety of responses in stream channels can be a result of natural and man-made activities. The Muda River has been dramatically affected by unsustainable human activities that sacrifice environmental values for the sake of national development. The land that drains into this river has been cleared out for agriculture, industry and urban development. These activities work together to increase the amount of runoff entering the river, thereby exposing the ecosystem to the risk of flooding. Given that land use projects in the Muda River are expected to change in the near future (JICA, 1995), it is important to investigate how past activities effected the form of the river channel in order to predict flooding risks in the long term. By knowing the character and predicting the behavior of meandering rivers, it is possible to better manage and plan land usage projects, especially when down-valley migration and lateral channel shifts occur that lead to the erosion of arable land and natural reserves. Thus both spatial and temporal changes are possible within the river area (Richards et al., 2005). With recent advances in technology and computer interfaces such as geographical information systems (GIS), remotely sensed data collection and graphical computer interfaces, one is able to use computer modeling for studies in this area (Pender and Néelz, 2007; Sanyal and Lu, 2005; Islam and Sado, 2000).

In this paper, the results are presented from a study of the spatial and temporal changes in land–usage in the Muda River basin on a long timescale (1984-2003). By detecting the changes in land usage it is possible to predict changes to the Muda River and thus predict and preemptively communicate flood risks. Computer modeling can greatly improve the understanding of the long-term behavior of the Muda River and its flooding risks. In this study, a computer model was used where special attention was paid to incorporating information on land attributes. These simulations enable us to gain an understanding of with effects of past human activities in the river system and examine the relevant impacts of changes to land usage on the performance of the river through time. This spatial and temporal information is a necessary input for flood management and developmental planning in the Muda River area.

2.0 Site Description and flood history

The Muda River is the longest river in the state of Kedah, and it is situated in northern Peninsular Malaysia with its upstream coming from the northern mountainous area of the state. The river, which has a length of 180 km, flows toward the southern area of the state and has a catchment area of 4,210 km². Downstream, the river changes its course towards the west coast after passing the confluence of the main stream and its largest tributary: the Ketil River. The three major tributaries of the Muda River system are: the Ketil river, the Sedim river and the Chepir river. Figure 1 shows the topography
of the Muda River basin. The annual rainfall in the study area is about 2,000 to 3,000 mm.

The Muda River is a major water supply and source for sand mining for the northern states. About 100 mining locations have created to extract sand from the river bed, far exceeding the natural total yield of sand for the river (JICA, 1995). This unsustainable use of resources has degraded the quality of the riverine system and made it vulnerable to severe environmental deterioration. The Muda River experiences floods almost every year, as the catchment often floods during the rainy seasons from April to May and from September to November. The annual flooding events only differ in magnitude. However, the flood history of the Muda River for the last 20 years indicates three major floods in 1988, 1998 and 2003 that caused extensive damage in terms of human lives and property. For example, 45,000 people incurred catastrophic damages as a result of the October 2003 flood (Julien et al., 2006). Problems associated with the catastrophic floods of the Muda River include riverbank erosion, river pollution and a
reduction of water resources. Riverbed subsidence seriously affects river structures such as bridges and water intake facilities. Moreover, the declining water level also causes difficulty in drawing water from the river at the existing intake points.

3.0 Methodology

3.1 Data and Software Requirements

The types of data used in this study for building the model of the 2003 flood event are: land use, soil, ground model (DEM), geometrical cross-sections, ground roughness (channel and floodplain), field observations, hydrographs from 1960 to 2007, and coastal tidal data.

3.2 Data Processing

3.2.1 Ground Data Extraction

In this study, a host of software packages were employed to extract and process several types of ground data. InfoWorks RS, a Wallingford software package, was used to build the computer model; InfoWorks RS is a combined 1D hydrodynamic ISIS Flow simulation engine with GIS functionality and database storage that can perform one-dimensional hydraulic modeling for a full network and provide input and output information in tabular and graphical formats. This system is capable of performing steady and unsteady flow water surface profile calculations. The main objective of using this software in this study is to provide information on the variation of river water levels, discharges, and velocities during flood events (Wallingford Software 2003).

The inputs of the model included the geometry data of the 261 existing cross sections between river mouth CH 0 and lading Victoria CH 41.2 at the upstream section of the Muda River. These data consist of lateral distances and elevations that were obtained from field surveys. The input hydrograph at lading Victoria from the 1st of January to the 31st of December, 2003 was used to simulate the 2003 flood that occurred from the 3rd to the 13th of October, 2003 (Figure 2). The peak flood took place on the 6th of October, 2003. The tidal record at the river mouth was used to define the time variation of the stage (water surface elevation) at a downstream cross-section. The geometry data, which were used to generate a digital elevation model (DEM), were obtained from field surveys. These data consisted of the lateral distances and elevations of thousands of points along the river’s path; the software ArcGIS 9.2 was used to extract the DEM.
Field observations were carried out by visiting the site on several occasions to identify the geographical attributes of the area. For this purpose, a mobile GIS environment in the personal digital assistant (PDA) device ASUS P535, which had fully operational ArcPad capabilities and GPS functionality, was used to collect the field data. The ground roughness data were assigned values for each zone to simplify digital processing in the

Fig. 2 Model input hydrograph and tidal information of the Muda River (Julien et al., 2006)
constructed model. The following ground roughness data values were recorded: (i) the vegetation, (ii) the substrate material (bed material, bank material or ground material) (iii) and an irregularity component. The floodplain vegetation components were divided into the following sub-categories: (1) trees, (2) crops, (3) grass and (4) hedges.

The roughness zone gives a description of the characteristics of a particular terrain type from which a roughness value for that terrain type is calculated. In order to define areas on the ground with a certain terrain type, roughness polygons derived from digital SPOT-5 space imagery (2.5 m) were created and visualized using the GeoPlan View. Each polygon was then assigned to a roughness zone ID field that was classified under an appropriate reference zone. The soil vector data were incorporated into the ground zones in areas where the soil was a defining geographical attribute.

The difference between the water levels depends on the parceling and the defined values of the ground roughness. Manning's roughness coefficient values were used in Manning's formula to calculate the flow in the open flow channels. Each ground material has roughness coefficient \( n \) that may be assigned a particular value for conditions that exist at the time of a specific flow event, average conditions, or anticipated conditions at the time of a future event. The roughness coefficient is generally considered to have the most uncertainty of any hydraulic or hydrologic variable in this type of model. The bed material and average grain size; surface irregularities of the channel; channel bed forms; erosion and depositional characteristics; meandering tendencies; channel obstructions; geometry changes between channel sections; and vegetation along the bankline and in the channel are all factors that affect the channel roughness (see figure 3). According to the velocity formula (1), an increase in the Manning coefficient of roughness \( n \) leads to a decrease in the velocity, and thus the water level will increase:

\[
V = \left( \frac{k_n}{n} \right) \cdot R^{2/3} S^{1/2} \quad \text{(1)}
\]

where

\( V = \) cross-sectional average velocity (ft/s, m/s)
\( k_n = 1.486 \) for English units and \( kn = 1.0 \) for SI units
\( A = \) cross sectional area of flow (ft\(^2\), m\(^2\))
\( n = \) Manning coefficient of roughness
\( R = \) hydraulic radius (ft, m)
\( S = \) slope (ft/ft, m/m)
3.2.2 River channel form analysis

The form of a river channel reflects the interaction between the discharge and sediment load with the materials in the river flows and the vegetation along its course. These interactions can also be expressed in other terms such as their characteristics along a cross-section or long profile. Channels that are formed in erodible sediments can be described as unconfined (alluvial or self-formed) channels and they may be subject to changes in location and form over time (Fookes et al., 2007). The properties of a channel interact in complex ways depending on the type of disturbance, the channel’s morphological characteristics, and the type and density of the surrounding vegetation. Expected channel responses to changes in the peak flow and water yield include bed coarsening, bank erosion, pool scour, and in extreme cases, channel incision (Knighton, 1998). Under stable climatic conditions, the alluvial channel geometry is often assumed to be in equilibrium with the prevailing flows, slope gradient, sediment type, bank vegetation and valley constrictions. Empirical equations can be used to predict the changes to an alluvial channel (Hey, 1997).

The channel form analysis used in the current study was based on the channel type classification system of Rosgen (1994) (see Figure 4). For this study, the channel pattern of the Muda River was described in terms of its sinuosity, \( S \), which can be expressed by the equation:

\[
S = \frac{L}{l} \quad (2)
\]

where \( L \) is the channel length and \( l \) is the straight-line valley length over a chosen distance. As with alluvial channels, the bedrock channel sinuosity is a function of the river discharge, channel gradient, sediment flux, and substrate erodibility; rivers will remain straight if little or no lateral erosion occurs. The development of bedrock channel sinuosity indicates high lateral (bank) erosion relative to the bed (vertical) incision and increasing sinuosity is a key mechanism that causes rivers to widen their valleys downstream or over time. Increasing rock uplift promotes a high bed incision potential leading to deep, narrow and straight channels; by contrast, a declining incision rate (which is usually coupled with reduced bed load flux and channel alleviation) favors bank erosion and increased sinuosity (Jansen et al., 2006).
3.2.3 Flood Model Setup

To construct our model, AutoCAD data on 261 cross-sectional geometries of the river were imported into the InfoWorks RS environment. They were then collated with raster data, GPS point data and Vector GIS data under the unified projection of WGS84. A schematic of the flood model is provided in Figure 5. The cross-sectional geometries were updated and manipulated in a way such that they were connected by lines in the GeoPlan view. The cross-sections were linked together to form a continuous river bed feature. Two boundary nodes were added to fit the limits of the hydrograph and tidal stage within the studied time period.
Fig. 5 Flowchart of the methodological approach to flood modeling in the GIS environment

A steady run type was chosen for the 1D hydrodynamic simulation, and the result from this simulation was used as the input for the unsteady run type simulation. Under both steady and unsteady conditions, InfoWorks RS computes the flow depths and discharges using a method based on the equations for shallow water waves in open channels: the Saint-Venant equations, which consist of a continuity equation (Equation 3) and a momentum equation (Equation 4). The solution of these equations defines the propagation of a flood wave versus the distance along the channel and time. For the continuity equation we have:

\[ B \frac{\partial y}{\partial t} + \frac{\partial Q}{\partial x} = q \]  

\[ \text{(3)} \]

where \( y \) is the stage, \( Q \) is the discharge, \( B \) is the stream’s top width, \( q \) is the lateral flow into the channel per unit length of channel (e.g. overland flow or ground water return flow), \( x \) is the distance along the channel, and \( t \) is time. For the momentum equation we have:

\[ S_f = S_0 - \frac{\partial y}{\partial x} - \frac{V}{g} \frac{\partial V}{\partial x} - \frac{1}{g} \frac{\partial V}{\partial t} \]  

\[ \text{(4)} \]

where \( g \) is the gravitational acceleration, and \( S_f \) is the friction slope. The friction slope is defined as:

\[ S_f = \frac{Q^2}{K^2} + \frac{n^2 Q^2}{A^2 R^{4/3}} \]  

\[ \text{(5)} \]
where A is the flow area, K is the conveyance, R is the hydraulic radius, and n is the Manning roughness coefficient.

The cross-sectional average flow velocity used hereafter is defined as \( V = \frac{Q}{A} \). The stage, \( y \), and the discharge, \( Q \), are the dependent variables that are determined by the simulation. The time, \( t \), and distance, \( x \), are independent variables, and all of the other variables are functions of the dependent or independent variables. The InfoWorks RS model uses a four-point, implicit, finite difference approximation to solve the Saint-Venant equations in full with the proper boundary conditions. The scheme is structured so as to be independent of the specific wave description (kinematic, diffusive or dynamic).

4. Results and Discussion

4.1 Channel form analysis

After applying Equation (2) to the Muda River, the sinuosity, \( S \), of the river channel was calculated as:

\[
S = \frac{41.826 \text{ (km)}}{26.8 \text{ (km)}} = 1.561
\]

The \( S \)-value of 1.561 clearly indicates that the Muda River is an ‘actively meandering’ channel. This type of channel is associated with alluvial channels that undergo almost constant re-adjustment in response to variations in the discharge and sediment load, or they have an inherent instability (Fookes et al., 2007). The calculated sinuosity (\( >1.4 \)) indicates that Muda River is of Stream Type C, according to Rosgen’s channel type classification system, and is characterized by: a dominant low gradient slope range (less than 2%, gentle slope); a meandering landform with alluvial soils; point bar features; a width to depth ratio larger than 12; a riffle pool bed morphology; and it is slightly entrenched with a broad and well-defined meandering channel. In this type of channel the water-flooding behavior extends towards prone areas beyond the limits of the river’s cross-section. The entrenchment ratio of this river is high (\( >2.2 \)), indicating increases in bank failures, the bed material grain size, susceptibility to erosion, and, in extreme cases, channel incision.

Figures 6 and 7 illustrate the temporal cross-sectional and longitudinal changes in the channel bed of Muda River within the past 20 years, respectively. Figure 6 shows that active lateral erosion occurred on the river banks during the last 20 years and, as a result, the river’s cross-sectional profile widened. Figure 7 shows the impact of selective erosion on a longitudinal profile of the river where erosion was active on the channel bed (vertical), causing river incision downstream relative to the upstream areas (far from river mouth).

Within the 20-year period examined here, the study area experienced increasing rates for the following anthropogenic activities: urbanization (4%), agriculture (1.35%), and land
clearing (1.2%), as shown in Figure 8. As more land cover is cleared out or altered by human activities, the combined influence of manmade structures and climatic changes, such as high rainfall over a short period of time (JICA, 1995), accelerate the channel’s broadening and thus facilitate more instability in the banks and erosion. Tree clearing influences the water yield in the stream while also changing the timing of the peak flow (MacDonald and Stednick, 2003; Jones and Post, 2004). The removal of the forest canopy causes a decrease in interception and transpiration in a basin, and a decrease in transpiration leads to an increase in the storage of water in the soil (MacDonald and Stednick, 2003). These changes can also increase the soil moisture content by allowing more water to drain into the channels. Apart from these effects, tree clearing from logged sites can also cause an increase in erosion and subsequently increase the sediment yield (McGurk et al., 1996). Also, harvested areas can contribute up to five times more sediment than undisturbed sites (Motha et al., 2003). In terms of the potential channel responses to increased discharge, the riverine system can experience changes in the width to depth ratio of the channel due to greater undercutting at the banks and the movement of sediment and wood in the streams (Montgomery and Buffington, 1997). As the channel boundary erodes, it causes changes to the grain size and bed form geometry, leading not only to an increase in the sediment transport capacity but also to an increase in the pool scour or channel incision (Liébault et al., 2002; Marston et al., 2003). This bed incision can be accelerated further at points in the river where cohesive bank material, root reinforcement, or bedrock exposure limit bank erosion (Fonstad, 2003). In addition, when an increased sediment load is present and the channel becomes unable to transport that load the river experiences aggradation, channel widening, bed fining, and pool filling (Rathburn and Wohl, 2003).

![Graph comparing bed levels](image)

**Fig. 6** Comparisons of the Present Cross-Section (New Bridge) and the Cross-Section from the Year 1993 (Old Bridge) (Julien et al., 2006)
The overall impact of the disequilibrium in the erosion-sedimentation mechanism in the river bed causes the instability of the river system. As a consequence of this unbalanced system, many land areas in the Muda River area are prone to the hazard of flash flooding as a result of the deteriorated channel conditions.
4.2. Flood modeling & analysis

Figure 9 shows the flow analysis results and a ranking of the flooding events of the Muda River over a 44-year period. The results indicate that the 2003 flood event had the highest discharge measured during the specified period, where a discharge of 1,340 m$^3$/s was measured (based on measurable peak discharges at Ladang Victoria station). The flood frequency analysis by Gumbel Extremal Type I shows the 50-year flood peaks between 1,254 and 1,275 m$^3$/s in Figure 10. In this figure, the 2003 flood discharge of 1,340 m$^3$/s was slightly larger than the 50-year peak discharge. Consequently, this value was considered as the design peak discharge for the lower Muda River (Julien et al., 2006).

![Fig. 9 Flood peaks of the Muda River from 1960 to 2005](image1)

![Fig. 10 Flood Frequency Analyses for the Muda River @ Ladang Victoria based on Gumbel Extremal Type I for discharge data of 1960 to 2005](image2)
Figure 11 shows the cross-section of the river bed used in the model at two cross sections at different locations with different roughness types. The roughness zone is a summation of vegetation, manmade features and surface materials. Each individual roughness zone value was incorporated into the computational matrices from the roughness database in InfoWorks RS. The simulation results shown in the two figures indicate that the model helped quantify the maximum and minimum water levels. It is shown that urban land use can be exposed to the maximum water level of about 2 meters. This water depth is classified as moderate hazard depth, according to a Japanese system (EXCIMAP, 2007). This important information will be used as input data or reference to the mitigation plan in order to protect urban locations from future flooding events.

The flooding behavior of the Muda River is influenced by anthropogenic factors along with natural geomorphic and climatic factors. The expansion in Muda basin urbanization (i.e., road and pavement construction, buildings, drainage channels, bridges, hydraulic mining, fishing areas and sanitation work) during the past 20 years has caused an increase in the discharge of the river due to an increase in the impervious areas. For instance, paved streets, concrete structures and sewage systems in the urban areas of the Muda basin carry runoff quickly to the stream and result in a significantly higher hydrograph
flow in a shorter length of time. The stream discharge rises and falls in urbanized areas much faster than in rural areas (Hyndman and Hyndman, 2006). The roads approaching bridges that commonly cross the floodplain are above the planned flood level. This involves filling materials (which may change the surface roughness) and creating a partial barrier across the floodplain so that the river flow is restricted to the open channel under the bridge. In addition, deeper water flowing under the bridge flows faster, causing erosion in the channel under the bridge and thereby increasing the sediment transport. The effect of streambed sand mining in the study area worsens the situation by deepening the channel and thereby increasing the erosion and sedimentation rate. Vegetation covering the Muda area has been long under stress because of unsustainable human activities such as deforestation, logging and over grazing. This has been an important input for the riverine system’s disequilibrium, as the removal of vegetation increases the vulnerability of the surface material. These manmade factors cause the sediment transport capacity of the Muda to increase and disturb the whole system’s equilibrium and facilitate the recurrence of flooding.

4.2.1 InfoWorks RS calibration

Figure 12 shows the calibration results of predicted water level for the two cross sections at CH 41.2 and CH 14.2 projected against observed water levels for different Manning values based on the hydrograph of the 2003 flood (Figure 2). For a Manning value of 0.03 for the main channel, the predicted values for the water level agree the best with the observed values. Therefore, this Manning value was used in the simulations.
Using the discharge data in InfoWorks RS for processing the model, the behavior of the 2003 flooding event was readily simulated and visualized graphically as shown in Figure 13. The figure shows the rapid flashing, wide spatial extension and depth at the early hours of flooding, which caused widespread damage to the surrounding landscape. The model also indicated that the maximum depth of the flood within the channel was greater than 18 m.
4.2.2 InfoWorks RS Simulation

Figure 15 shows the simulated water profile for the 1984 flood (Figure 14), which can be compared with that of the 2003 flood (Figure 2). The flood hydrographs were used to represent the effect of land usage change over the last 20 years (1984-2003). As a result of land use changes due to rapid development in the river basin, the water level has dramatically increased in the past 20 years. The removal of the vegetation cover and sand mining activity are expected to give rise to river bed degradation and bank instability.

Fig. 14 Hydrograph of the 1984 Flood

Fig. 15 Comparison between the 1983 and 2004 flood conditions
Comparisons on the effects of recent floods in 2003 (Figure 2) and 2005 (Figure 16) are given in Figure 17. Table 1 shows wet paddy is more susceptible to flooding compared to other landuses. Also, the total inundated areas for 2003 flood is almost double that of 2005 flood. The number of houses inundated in 2003 flood is given in Table 2 according to different water levels. As a result of the 2003 flood, a flood mitigation project was initiated and is being implemented involving river widening and the construction of levee on both banks of the Muda River. This project is expected to give protection to the economy activities along the Muda River.

Fig. 16 2005 Flood Hydrograph
(a) December 2005 peak flow flood (CH 15.00 – CH 20.00)

(b) October 2003 peak flow flood (CH 15.00 – CH 20.00)

Fig. 17 Inundated areas for 2003 and 2005 floods
Table 1 Simulated Inundation Areas according to Land Use Categories

<table>
<thead>
<tr>
<th>Land use Category</th>
<th>Inundation areas for 2003 flood (× 1000 m²)</th>
<th>Inundation areas for 2005 flood (× 1000 m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>8,696</td>
<td>2,600</td>
</tr>
<tr>
<td>Rural</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Rubber, oil palm, coconut</td>
<td>9,021</td>
<td>3,634</td>
</tr>
<tr>
<td>Wet paddy</td>
<td>11,758</td>
<td>6,684</td>
</tr>
<tr>
<td>Others (grass, clear land, shrubs)</td>
<td>4,905</td>
<td>3,773</td>
</tr>
<tr>
<td>TOTAL</td>
<td>34,390</td>
<td>16,694</td>
</tr>
</tbody>
</table>

Table 2 Simulated Inundation Areas for Urban Areas during 6th October 2003 Flood

<table>
<thead>
<tr>
<th>Inundation Depth (m)</th>
<th>Inundated Area (× 1000 m²)</th>
<th>No. of Inundated Houses</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.5</td>
<td>712</td>
<td>183</td>
</tr>
<tr>
<td>0.5 - 1</td>
<td>1,374</td>
<td>444</td>
</tr>
<tr>
<td>1 - 1.5</td>
<td>1,687</td>
<td>523</td>
</tr>
<tr>
<td>1.5 - 2</td>
<td>1,934</td>
<td>680</td>
</tr>
<tr>
<td>2 - 2.5</td>
<td>1,238</td>
<td>366</td>
</tr>
<tr>
<td>2.5 - 3</td>
<td>566</td>
<td>107</td>
</tr>
<tr>
<td>&gt;3</td>
<td>1,185</td>
<td>314</td>
</tr>
</tbody>
</table>

Conclusions

Erosion and sedimentation are dynamic processes resulting from the interaction between the flowing water and sediment bed. The model developed in this study is a valuable tool for analyzing the numerous proposed flood mitigation options and flood risk management.

The channel form analysis of the Muda River presented in this paper does imply that the stream is Type C, as indicated by its high sinuosity S>1.4. The changes to the cross-sectional and longitudinal profiles of the stream channel that occurred within the last 20 years indicate both active lateral erosion on the banks (widening of the river) and vertical erosion on the river bed (channel incision). This erosion, which is a result of the geomorphological meandering nature of the Muda River system, has serious implications for engineering activities in this area. In addition to that, other factors such as new land usages also worsen the state of the river.

It can be seen that within a time frame of 20 years human activities have changed many features of this river system. In addition, activities such as land clearing, deforestation, and urbanization have exposed the river system to erosion hazards and a reduction in the general surface roughness of the ground. Since the flood plain of Muda River is expected to host more development in the future, more of the land will be vulnerable to erosion.
hazards and, consequently, subject to the risk of flooding. This result is supported by the flood modeling software InfoWorks RS. By using this computer simulation tool, one is able to indicate the high potential high risk areas of the Muda River. In addition, this study can help developers and authorities in the Muda area make decisions and take action on flood prevention measures.

References


Department of Irrigation and Drainage Malaysia. (2000). Urban Stormwater Management Manual for Malaysia or MSMA.


