

## LOSS OF STORAGE AREAS DUE TO FUTURE URBANIZATION AT UPPER RAMBAI RIVER AND ITS HYDROLOGICAL IMPACT ON RAMBAI VALLEY, PENANG, PENINSULAR MALAYSIA

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**Abstract:** *Rambai Valley is a coastal floodplain located in Penang northwest coast of Peninsular Malaysia. It is undergoing substantial urbanization at present. This valley is drained by two main channels, Rambai River and Canal 4. The paddy fields of the upper section of Rambai River and Canal 4 (Permatang Rotan) are flood storage areas. They attenuate part of the peak flows that enter the flood prone central region of this valley which is extensively urbanized. This paper through statistical analyses examines the change in potential peak stages resulting from the present and future conversion of upper Rambai River paddy land to urban surfaces. The changes in potential peak stages are simulated using XP-Storm with the purpose of studying the impact of the loss of these storage areas on the downstream floodplain. Channel roughness and surface runoff flow time data were used for model calibration. Simulation results indicated that extensive loss of the paddy fields could lead to higher flood peaks to the immediate downstream sections, i.e. between 9% to 22% for 50% and 100% losses of storage area. The results also indicated that for the same percentage of storage area losses, flood peak stage increases 2.5 to 3.25 times higher for stream point located immediately downstream of the target area (i.e. 500 m away) compared to further downstream points (i.e. 3 to 6 km away) that showed no significant changes. As a whole, the results implied that the increase and propagation of peak stages downstream is not proportional (rational) to the percentage of urbanization and loss of storage areas. The impact of urbanization on peak stage is declines with increasing distance from the target areas.*

**Keywords:** peak flow, floodplain, flood peaks, urbanization, unsteady flow, runoff

### 1. INTRODUCTION

Urbanization is the most forceful of all land use changes affecting the hydrology of an area.<sup>1</sup> It reduces storage capacities and shortened concentration time resulting in high peak flows that could cause floods with increasing frequency and magnitude.

The problems associated with increase of flow magnitude and frequency, are aggravated by the tendency for urban development to encroach on the floodplains of local watercourses, which reduces the amount of over-bank storage.<sup>2</sup> DeVries conducted a study on the effects of floodplain encroachments on peak flow in the United States.<sup>3</sup> It was found that when land development was permitted on river floodplains, the magnitude of the flood peak discharge would increase due to removal of flood plain storage. If the flood plain encroachment was limited, the study results indicated that the increase of flood peak was usually small, generally less than 10%. DeVries and Hall indicated that flood plain storage was an important factor in attenuating peak flows and in reducing flood levels.<sup>2,3</sup>

Authors comparative study of stream flow characteristics of seven watersheds with different degrees of urbanization in Atlanta, Georgia.<sup>4</sup> Based on stream flow record for the period from 1958 to 1995, the peak flows (storm flows) and base flows of the Peachtree Creek, a highly urbanized watershed (54.7%), were compared to two less urbanized watersheds (13% to 14%), and four non urbanized watersheds (0.5% to 4.0%). The results indicated that for 25 largest storm flows, the peak flows of Peachtree Creek were 30% to 100% greater than the peak flows in the other watersheds. Storm recession period of the same watershed was characterized by a 2-day storm recession constant that was 40% to 100% greater than others. This rapid recession of Peachtree Creek peak flows compared to other less urbanized watersheds indicates that it has a shorter lag time. Base flow for Peachtree Creek was 25% to 35% less than other watersheds possibly resulting from decreased infiltration caused by the more efficient routing of storm water and the paving of groundwater recharge areas. Their research indicated that urbanization causes higher variability of flows (higher peaks and lower low flows). Cheng and Wang conducted a study on the effect of urban development in Taiwan's Wu-Tu watershed.<sup>5</sup> They used 26 rainfall-runoff events (1966–1991) for the purpose of calibration and eight (1994–1997) events for validation of their research model. The comparative results of their instantaneous unit hydrographs of the study area revealed that three decades of urbanization had increased the peak flow by 27% and the time to peak was decreased significantly.

The authors applied a conceptual rainfall-runoff model to 95 catchments in the Rhine basin for the purpose of modeling of the effect of land use change on the runoff.<sup>6</sup> Land use, soil type, catchment size, and topographic structure were used as the bases for regionalization of their model parameters. Their regionalized model was used to model the resulting runoff for different land use scenarios generated in the model area. Their overall results suggested that increased urbanization leads to an increase in runoff peak whereas a considerable reduction of both the runoff peak and the total runoff volume resulted from intensified afforestation.

In the tropics, the effects of land clearing, which typifies the early stages of urbanization are well-demonstrated in the experiments conducted in the Tekam River Experimental Basin (natural basin), Peninsular Malaysia.<sup>7</sup> The experiments were conducted from July 1977 to June 1986. The results indicated that water yield increased by 157%, peak flow increased to 185%, time lag decreased by 67% and infiltration decreased by 33%–88% from pre-clearance conditions. The experiments discovered that base flow increased more significantly compared to direct runoff due to reduce evapotranspiration and ponding effects immediately after deforestation. The direct runoff did not increase significantly because the experiment at the basin was not subjected to urbanization. Ismail observed that the base flow (which generates peak flow) at Sungai Air Terjun Catchment (a forested catchment on Penang Hill, Malaysia) was consistently higher (87.3% of average flow) than the quick flow (12.7%).<sup>8</sup> These results pointed out that land clearing itself does not necessarily cause a significant increase in direct runoff or quick flow compared to a natural condition. In other words, the area has to be subjected to urbanization first. These results supported the conclusion of Rose and Peter.<sup>4</sup> Generally, urbanization would result in a significant reduction of base flow but an increase in direct runoff.<sup>4,9</sup>

The review above underlines a common fact that urbanization has quantifiable effects on the hydrologic behavior of a drainage basin that is experiencing urbanization. Lu identified three main approaches in estimating these effects of urbanization.<sup>1</sup> First, is to evaluate the effects and predict the future floods by using existing data. Second, is to use an experimental basin. Third, is to use watershed simulation model to simulate the effects. In this paper, the third approach is used to examine the hydrologic effects of urbanization on a study area.

## 1.1 The Study Area

Rambai Valley is located in the Juru River Basin, Penang, i.e. 5.325°N–5.39°N and 100.41°E–100.51°E (Fig. 1). It is about 43.0 km<sup>2</sup> in size. It is bordered by isolated hills succeeded almost abruptly by narrow depositional lowlands and drained by Rambai River (75% of the total area) and Canal 4. Both channels flow into Juru River which connects this valley to the Penang Straits about 8.1 km away.

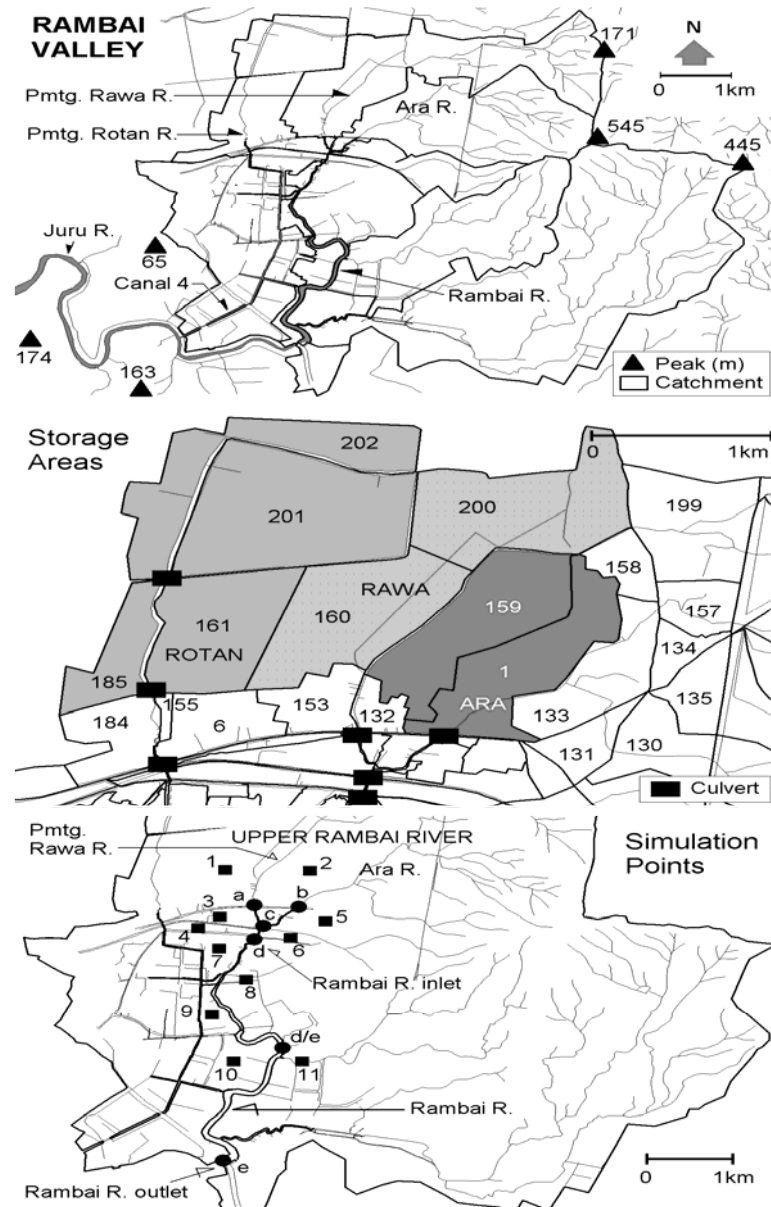


Figure 1: Study area.

Naturally, Rambai Valley is a flood prone area due to its low-lying topography.<sup>10</sup> Over the last two decades (1980–2000), this largely agricultural region has experienced rapid urbanization resulting in the loss of paddy fields and

natural wetlands as they are converted into residential, commercial and industrial (small and medium scale) areas. The total percentage of urban areas in the Juru River Basin has increased from 17.2% to 46.8% between 1982 and 1995.<sup>11</sup> It is estimated that 77.6% of this basin would be urbanized by 2010.<sup>12</sup> In consequence, surface runoffs have increased causing floods to occur almost every year since 1984 mostly between September and October when the inter-monsoon period brings heavier rainfalls on the northwestern region of Peninsular Malaysia.<sup>13</sup> Hence, since early 1980s the occurrence of floods in Rambai Valley has been attributed to urbanization.<sup>14</sup>

The paddy fields and wetlands of Rambai Valley serve as flow storage areas. They attenuate and delay peak flows through their storage function.<sup>15</sup> The main storage areas for Rambai Valley are: 185, 161, 201 and 202 for Permatang Rotan tributary; Units 160 and 200 for Permatang Rawa tributary and; Units 159 and 1 for Ara River tributary (Fig. 1). This paper focused on the upper storage areas of Rambai River only, i.e. Permatang Rawa and Ara River. The storage or paddy field area for Permatang Rawa is 149 ha whereas for Ara River is 124 ha. However, their total storage area is much larger because it includes overflows into units such as 161, 201, 153, 132, 133 and 158. Thus, the total storage area for Permatang Rawa is 310 ha whereas for Ara River, it is 186 ha. The storage area and culvert effects work in conjunction with each other (Fig. 1). The culverts offer resistance to outflows which in turn cause backwater rise. The backwater rise causes overflow from the tributaries into the storage areas and also flood some settlement areas. Apart from that, there are also direct overflows from the tributaries into storage area during high peak flows. This paper studies the probable change in potential peak stages downstream consequent to future conversion of these storage areas into urban areas.

## 2. METHODOLOGY

In this study, three scenarios are examined:

Scenario 1: This scenario represents the present condition where the land covered of Permatang Rawa and Ara River is assumed to be the same as the land covered of 2001 (Table 1). The size of paddy lands is assumed to be unchanged or in other words no urbanization has taken place.

Scenario 2: 50% of the paddy fields of Units 160 (Pmtg. Rawa), 159 and 1 (Ara River) are assumed to be urbanized in the near future (2010). It should be noted that under the local development plan, a large part of the paddy fields of Permatang Rawa and Ara River is planned for urbanization by 2010.

Scenario 3: 100% of the paddy fields of Units 160 (Pmtg. Rawa), 159 and 1 (Ara River) are assumed to be urbanized in the near future (2010).

Scenarios 2 and 3 represent 4.25% and 8.5% increase of urban surfaces on Rambai River basin (32.25 sq. km.), respectively. These values were selected according to the projected 2010 land use of this area as stated in the local government development plan.<sup>12,14</sup>

Table 1: Upper Rambai Valley land cover – 2001.

Land Cover	Area (ha)	%
Paddy field	212.34	28.73
Construction bareland	59.76	8.09
Grassland - wetland	12.67	1.71
High density built-up area	81.54	11.03
Low density area (villages)	203.53	27.54
Road	10.96	1.48
Forest	158.24	21.41
<b>TOTAL</b>	<b>739.04</b>	<b>100</b>

The potential flows resulting from urbanization under each scenario at catchments level were simulated using a semi-lumped Rational Method whereas the flows in the tributary channel systems, i.e. Permatang Rawa and Ara River, and the trunk river, i.e. Rambai River were routed using the one-dimensional dynamic wave model, Equation 1 and 2.<sup>16</sup> This one-dimensional hydraulic model is suitable for tidal affected or unsteady flow conditions such as Juru River.<sup>17</sup> XP-Storm software was used to compute the dynamic wave equations. The semi-lumped Rational Method uses spatial and temporal varied rainfalls and spatially varied composite runoff coefficients, Equation 3 and 4. Conventional Rational Method assumed rainfall is evenly distributed through time and space, and a single runoff coefficient value for a whole basin. In the semi-lumped Rational Method, rainfall variability was taken into account in the model by distributing hourly rainfall isohyetal values upon a drainage basin first decomposed into spatial cells.<sup>18,19</sup> Each of the cells will also has different composite runoff coefficients computed according to its land cover types. Computation and distribution of rainfall, and composite runoff coefficients were automatically done by using Arc View GIS.

The conservation form of the dynamic wave equations is given below.  
Continuity:

$$\partial Q / \partial x + \partial s_{co} (A + A_0) / \partial t - q = 0 \quad \text{Eq. 1}$$

Momentum:

$$\begin{aligned} \partial(s_m Q) / \partial t + \partial(\beta Q^2 / A) / \partial x + gA(\partial h / \partial x + S_f + S_i + S_e) - \beta q v_x + W_f B &= 0 \\ S_0 &= S_f \\ s_m = s_{co} &= \Delta x_c / \Delta x \\ L &= \beta q v_x \end{aligned} \quad \text{Eq. 2}$$

Where,

$x$  – longitudinal distance along the conveyance;  $t$  – time;  $A$  – cross-sectional area of flow;  $A_0$  – cross-sectional area of dead storage (off-channel);  $q$  – lateral inflow per unit length along the conveyance;  $h$  – water-surface elevation;  $v_x$  – velocity of lateral flow in the direction of flow;  $B$  – width of the conveyance at the water surface;  $W_f$  – wind shear force;  $\beta$  – momentum correction factor;  $g$  – acceleration due to gravity;  $S_0$  – bed slope;  $S_f$  – friction slope;  $S_e$  – eddy loss slope;  $s_m$  and  $s_{co}$  – channel sinuosity factor (meandering channel) where sinuous distance ( $\Delta x_c$ ) is divided with mean flow path of a particular section ( $\Delta x$ );  $L$  – momentum effect of lateral inflow

The rational formula is given as  $Q = C I A$ , where  $I = P/t$  and  $C = R/P$ . In the semi-lumped Rational Method, for  $t = t_1 - t_0$  as an example,  $Q = C I A$  of a drainage cell can be represented as:

$$Q(t_1 - t_0) = (R_1 - R_0 / P_1 - P_0) * (P_1 - P_0 / t_1 - t_0) * A = [(P_1 - P_0 * C) / \Delta t] * A = (\Delta R / \Delta t) A \quad \text{Eq. 3}$$

$Q$  – peak discharge in  $\text{m}^3/\text{s}$ ;  $P$  – rainfall in mm (convert to meter);  $A$  – area size or cell size in  $\text{m}^2$ ;  $R$  – surface runoff in mm (convert to meter) dependent on the runoff coefficient;  $C$  – composite runoff coefficient;  $I$  – rainfall intensity;  $t$  – time.

$$C_c = [C_1 * (X / A)] + [C_2 * (Y / A)] + [C_3 * (Z / A)] \quad \text{Eq. 4}$$

$C$  – runoff coefficient;  $C_c$  – composite runoff coefficient;  $C_1$ ,  $C_2$  and  $C_3$  – runoff coefficient of sub-cell land cover taken from published values;  $X$ ,  $Y$  and  $Z$  – land cover size for sub-cell area;  $A$  – cell area.

Since  $P$  can vary at different time interval and cell, and  $C_c$  can vary for different cells, cumulative  $Q$  for a whole drainage basin will be varied according to time accounting for spatial and temporal variability of  $Q$  at cell level.

Hence, the Rambai River basin is delineated into catchments with external channels (tidal affected) mentioned above. The catchments are decomposed into drainage cells. Two separate layers of modeling are used, hydrologic and hydraulic layer. The hydrologic layer computes flow from catchments located along the tidal affected external channels by employing the Rational Method at cell level while the hydraulic layer routes the unsteady flow in the external channel. Actual rainfall data taken from 23 to 25 October 1999 which represent a typical rainfall event during inter-monsoon period that normally brought heavy rainfalls in northwest Peninsular Malaysia.<sup>16</sup> The rainfall values are distributed into individual cells and the effects of urbanization is accounted for by changing the runoff coefficient value of affected cells. Flow simulation is subjected to actual boundary conditions (tidal flux) at the estuary of Juru River throughout the simulation period.

The separated layers modeling approach is necessary because the Rational Method cannot be employed under unsteady flow conditions (e.g. tidal affected channels) directly. This approach is drawn from the works of Shuy<sup>20</sup> and Stewart et al.<sup>21</sup> Shuy combined the lumped Rational Method with the dynamic wave model as two separate layers. The rational formula was used to generate upstream flow from a free flow area while the dynamic wave model was employed to route flow in a tidal affected channel with an outlet boundary condition. Stewart et al.<sup>21</sup> separated catchments from a floodplain. The catchments were modeled using a hydrologic model while the floodplain was modeled using a two-dimensional diffusion wave model.

Initially, the Rambai River stage hydrograph produced by the simulation was compared to actual stage hydrograph recorded by Drainage and Irrigation Department's water levelling station at Point 'e' for calibration purposes (Fig. 1). The model was calibrated by adjusting channel roughness coefficients (Manning's 'n') and surface runoff flow time. After that the model was simulated again.

The final simulation results consisting of river stages and flows along the Rambai River are first compared to each other based on their normalized stage or average stage (Figs. 2 & 3). The normalized stage was computed from the average of the sum of stage levels of each scenario for a particular sampling point under consideration. This is done with the purpose of graphically detecting the migration of these values under different urbanization scenarios. After that, the simulation results are statistically analyzed to examine the variation between



scenarios and also the relation of these variations with the increment of distance from the target area.

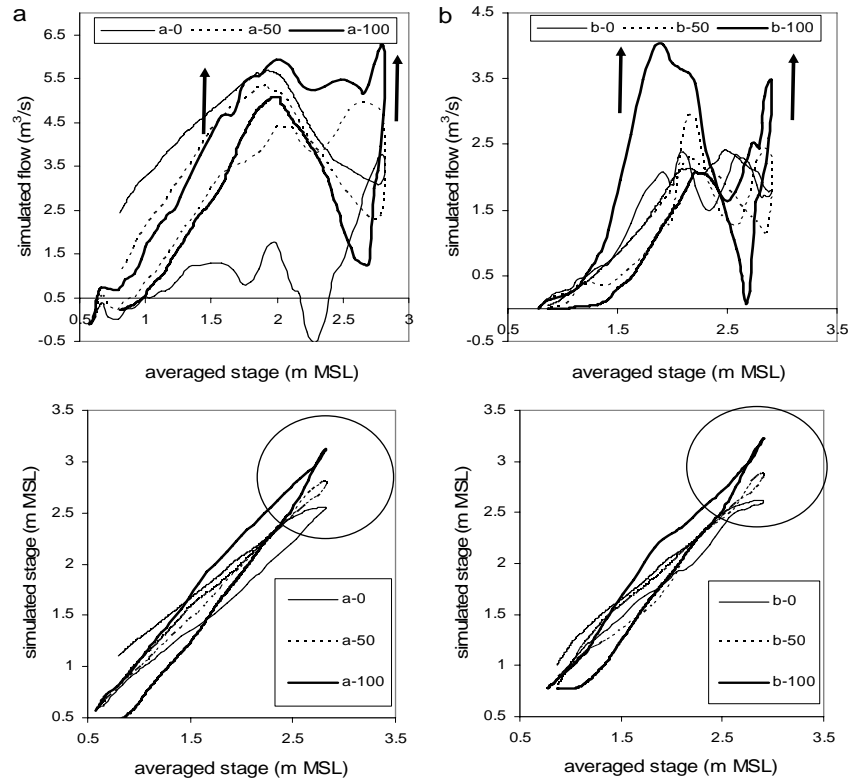


Figure 2: Migration of peak flows against normalized stage at Point ‘a’ and ‘b’.

Note: Arrows showing the upward migration of flow values.

The points where simulation results are compared are shown in Figure 1. They are divided into channel points (‘a’ to ‘e’) and catchments sites (1 to 11). The objectives of the statistical analysis are as stated below:

Within channel point comparison (Point ‘a’ and ‘b’ only)

To examine the variation of peak stage and flow between 0%, 50% and 100% urbanization in order to determine the impact of urbanization on the target/source areas. From this analysis, the proportional relationship between the proportionate increase of urbanization (i.e. from 0% to 100%) and peak stage/flow can be studied. The question is: Do both of them have a rational relation? This is a significant question because it proposes an idea that increased urbanization does

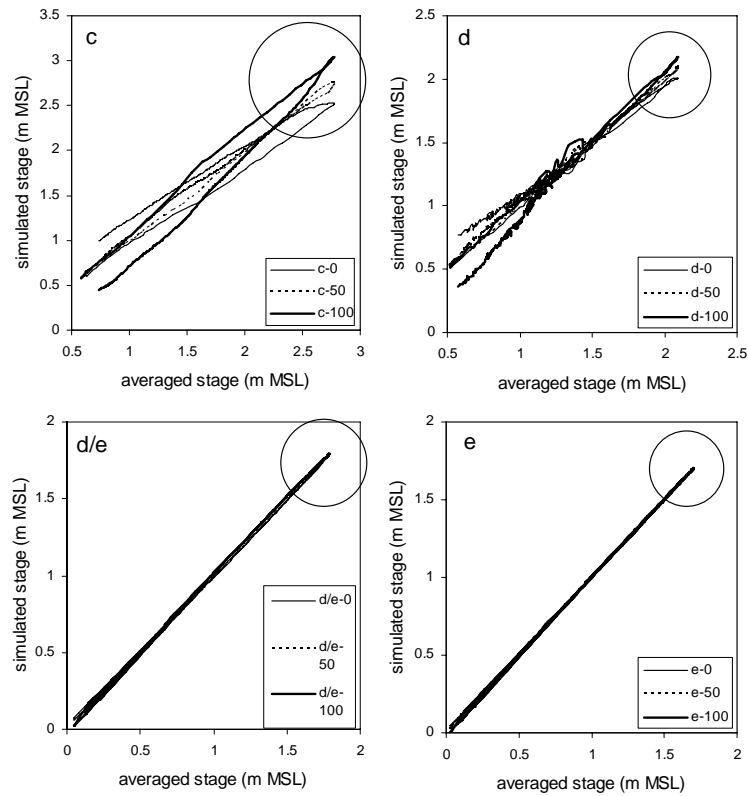


Figure 3: Migration of peak stages against normalized stage at Point 'c' to 'e'.

Note: c-0, c-50, c-100 to e-100 – represent stage values resulting from varying levels of urbanization; Circled areas mark out the peak stage.

not necessarily mean its quantifiable impact (peak stage and flow) is proportionate. Objective 1 uses descriptive statistics such as percentage of change, mean, frequency distribution, skew and variance.

#### Between channel points comparison

To examine the variation of peak stage in the external channel at specific distances or downstream points from the target areas. This is done in order to determine the level of peak stage propagation downstream or the transfer of urbanization impact from the target areas. Points examined are 'a', 'b', 'c', 'd', 'd/e' and 'e' with distance set at 0, 0.5, 0.75, 3.25 and 5.8 km. From this analysis, the transfer of quantifiable impact on downstream channel sections at specific distances can be shown. The relationship between variation of peak stage resulting from increased proportion of urbanization and increment of distance can be examined. This is to study how far the impact goes and whether the impact on

the immediate downstream section is significantly greater. Objective 2 uses the statistical techniques mentioned above in addition to ANOVA, Euclidean distance and Pearson's correlation.<sup>22,23</sup> For further analysis on peak stages, third derivatives of third order polynomial curves that relate stage with distance are used.

Within and between catchments sites comparison (Sites 1 to 11)

To examine the variation/increase of flood levels caused by urbanization on the target areas and also catchments located downstream. This analysis would indicate the end result of converting the paddy fields which act as storage areas into impervious urban surfaces. Objective 3 uses a simple percentage of change technique.

### 3. RESULTS AND DISCUSSION

The flow curves or loops for both target areas, Permatang Rawa and Ara River showed an upward migration from their initial curve (a-0 and b-0) (Fig. 2). This indicates an increase of flows against normalized stage consistent with the loss of storage areas to 50% and 100% urbanization. As a result, the stage-flow relations for both Points 'a' and 'b' showed positive feedback resulting from increased runoffs from 'new' urban surfaces on the paddy fields.

The peak flow for Permatang Rawa outlet or Point 'a' has increased from 5.682 m<sup>3</sup>/s in Scenario 1 to 6.269 m<sup>3</sup>/s in Scenario 3 (10.33% increment) whereas its peak stage, from 2.557 m in Scenario 1 to 3.120 m in Scenario 3 (22.02% increment). As for Scenario 2, the result for Point 'a' is apparently anomalous. Its peak flow indicated a slight decrease at 5.368 m<sup>3</sup>/s whereas its peak stage was at 2.803 m or 9.06% higher than the initial scenario. A closer analysis showed that at the higher stage level (2 to 3 m), Scenario 2 of Point 'a' generally has higher flow values than its initial scenario, i.e. 4.11 m<sup>3</sup>/s compared to 3.8 m<sup>3</sup>/s on average. Moreover, Scenario 2 of Permatang Rawa did indicate an increment of flows but at a higher stage level. It should be noted that Rambai River has an unsteady flow affected by tidal inflows hence the stage-flow relation of this hydrological system did not have a constant proportionate relation. Moreover, a larger flow did not necessarily imply a higher stage or otherwise. Hence, in later analysis stage is used as a proxy to examine the impact of urbanization since flood occurrence could be directly linked to overflows caused by high stage. As for Ara River outlet or Point 'b', its peak flow has increased from, 2.4 m<sup>3</sup>/s initially to 3.0 m<sup>3</sup>/s in Scenario 2 and 4.01 m<sup>3</sup>/s in Scenario 3. These increments are equal to 25% and 67% increase of peak flow compared to their respective initial peak flows. Similar to their percentile change of peak flow, the peak stage of Points 'a' and 'b' (i.e. Scenario 2: 9.06%; Scenario 3: 22.02%) did not increase

in the same proportion as the increased of urban surfaces which is 50% and 100%. This implies that the quantifiable impact of urbanization does not necessarily have a rational relation with the proportionate increase of urbanization. In fact, the peak flow may even decreased as shown in Scenario 2 of Point 'a'.

The mean stage values of Points 'a' and 'b' indicated that the stage levels from both tributaries have generally decreased although their peak stage increased as a result of their hydrologic behavior modification caused by urbanization and the loss of their storage capacities (Table 2). At the same time, their variance indicated greater variability in stage levels as urbanization increased from 0% to 50% and 100%. Both points showed a shift from negative skew values,  $-0.43$  and  $-0.12$  (0% urbanization), to positive skew values of  $0.23$  and  $0.4$  (100% urbanization). This shift and increase in variance implied that the stage values were more varied and have a tendency towards lower stage values. The frequency distribution for Points 'a' and 'b' indicated that Scenarios 2 and 3 had higher percentage of low and high stage values compared to Scenario 1. Scenarios 2 and 3 of Point 'a' had 14% and 27% cases of low stage respectively (0.50 to 1.00 m MSL) compared to Scenario 1 which is 9%. As for Point 'b', it had 26% and 37% cases of low stage (0.75 to 1.25 m MSL) for the same scenarios compared to Scenario 1 which was 20%. Likewise, Scenarios 2 and 3 of Point 'a' had 2% and 6% cases of high stage (2.75 to 3.25 m MSL) compared to Scenario 1 which had none. Whereas, Point 'b' had 3% and 8% cases of high stage (2.75 to 3.25 m MSL) for the same scenarios compared to Scenario 1 which also had none. In comparison, there were obviously more cases of low stage for Scenarios 2 and 3 compared to high stage which account for their positive skew values. Hence, the mean stage levels decreased with greater urbanization although the peak stages increased. In short, urbanization could cause greater variability in stages with 'spikes' of higher peak stages whereas a non-urbanized condition appears to produce a more modulated condition.

The effects of increased peak flows from Permatang Rawa and Ara River sub-basins can be detected by examining the change of stage levels downstream. Simulation Points 'c', 'd', 'd/e' and 'e' were used for this purpose. Point 'c' represents the immediate downstream point and also the convergence point for the tributaries. It is located about 0.5 km from their outlets. Point 'd' represents the inlet point for Rambai River floodplain. Point 'd/e' represents the halfway point between the inlet and outlet of Rambai River whereas Point 'e' represents the outlet point for Rambai River floodplain plus the whole Rambai Valley itself. These points were located 0.75, 3.25 and 5.8 km away from the outlets of Permatang Rawa and Ara River, respectively.

Table 2: Descriptive statistics of simulation points.

Points	min-stage (m MSL)	max-stage (m MSL)	mean	variance	skew
a-0	0.57	2.56	1.73	0.27	-0.43
a-50	0.57	2.80	1.70	0.33	-0.12
a-100	0.48	3.12	1.58	0.52	0.23
b-0	0.78	2.62	1.77	0.26	-0.12
b-50	0.78	2.88	1.74	0.33	0.03
b-100	0.78	3.23	1.64	0.50	0.40
c-0	0.58	2.53	1.66	0.27	-0.28
c-50	0.58	2.76	1.63	0.34	-0.02
c-100	0.45	3.05	1.52	0.52	0.28
d-0	0.51	2.01	1.22	0.17	0.50
d-50	0.52	2.10	1.20	0.20	0.55
d-100	0.36	2.17	1.14	0.28	0.52
d/e-0	0.07	1.79	0.78	0.27	0.72
d/e-50	0.05	1.79	0.78	0.28	0.70
d/e-100	0.02	1.80	0.78	0.29	0.67
e-0	0.05	1.70	0.74	0.25	0.70
e-50	0.03	1.70	0.74	0.26	0.69
e-100	0.00	1.70	0.73	0.26	0.67

Note: a-0 to e-0 – Scenario 1; a-50 to a-50 – Scenario 2; a-100 to e-100 – Scenario 3

The stage levels of each point were plotted against its normalized stages in order to detect the migration of stage levels for Scenarios 2 and 3 compared to the initial conditions or Scenario 1 (Fig. 3). The circled areas mark out the peak stages. Point ‘c’ clearly showed a greater migration of peak stages for 50% and 100% urbanization. Its peak stages migrated upward between 0.23 to 0.52 m from the initial level of 2.53 m MSL. Its overall values represented by each curve were dispersed from each other with Scenarios 2 (c-50) and 3 (c-100) showing higher peak values than the initial curve (c-0) or Scenario 1. Point ‘d’ indicated a lesser upward migration of peak stages but a greater dispersion at lower stages. The greater dispersion of lower stages implied a higher storage release from its immediate upstream storage areas (around Point ‘c’) during the flow recession phase. The lesser upward migration of peak stages indicate that the effects of greater outflows from Permatang Rawa and Rawa River have been attenuated by storage areas of its immediate upstream or Point ‘c’. This assertion could be substantiated by the results of analysis on flood depths discussed later. Point ‘e’

showed the least changes in peak stages. There is no significant dispersion between the stage curves. This indicates that the effects of greater outflows from Permatang Rawa and Ara River are not significant at the outlet of Rambai Valley as the storage areas along Rambai River including the channel storage itself attenuate the increased outflows. These phenomena can be supported from the results of the statistical analysis carried out (Tables 3 & 4). The ANOVA results showed that the  $F$  statistic for Points 'a', 'b' and 'c' are higher than their  $F$  critical value with their probability levels below the significance level, i.e.  $\alpha = 0.05$ , whereas for Points 'd', 'd/e' and 'e', their  $F$  statistics are lower than their  $F$  critical value with probability levels above 0.05. Hence, the null hypothesis for Points 'a', 'b' and 'c' is rejected because there is a significant variation between their stage levels. As for the other points, the results indicated that there is no significant variation between them. Thus, it could be assumed that as a whole the points that are located nearer or at the target areas have greater variation in their stage levels resulting from the impact of greater urbanization while points located further downstream do not. The covariance and the Euclidean distance index of Scenarios 2 and 3 against Scenario 1 generally implied a lower variability with increasing distance from the target areas. In comparison, the Euclidean distance index gives a better indication of variation between scenarios than covariance. This index clearly indicates that Scenario 3 has higher variability against Scenario 1 compared to Scenario 2 against Scenario 1. This is consistent with the fact that Scenario 3 represents 100% urbanization while Scenario 2, 50%. Nonetheless, the ANOVA results showed that the variations that exist for points located further from the target areas, i.e. 0.75 to 5.8 km away (Points 'd' to 'e'), are not significant. In other words, these analyses implied that impact of urbanization decreased with distance downstream.

Table 3: ANOVA - Single factor between scenarios.

Points	$F$	p	F-critical	Type I Error
A	4.537	0.01	3.007	reject
b	3.543	0.03	3.007	reject
c	4.145	0.02	3.007	reject
d	2.392	0.09	3.007	accept
d/e	0.008	0.99	3.007	accept
e	0.015	0.99	3.007	accept

Significance level:  $\alpha = 0.05$

Table 4: Scenarios 2 and 3 compared to Scenario 1.

Points	Distance (km)	covariance	Euclidean distance	peak range (m)	mean range (m)
a-50	0	0.293	2.142	0.24	-0.035
b-50	0	0.287	1.597	0.26	-0.035
c-50	0.5	0.3	1.903	0.23	-0.032
d-50	0.75	0.181	0.99	0.09	-0.015
d/e-50	3.25	0.273	0.153	0.003	-0.002
e-50	5.8	0.254	0.134	0.003	-0.002
				$R = -0.86$	0.88
				$p = 0.028$	0.021
a-100	0	0.333	6.133	0.56	-0.153
b-100	0	0.334	5.126	0.61	-0.135
c-100	0.5	0.346	5.66	0.52	-0.147
d-100	0.75	0.209	2.964	0.16	-0.083
d/e-100	3.25	0.282	0.281	0.006	-0.006
e-100	5.8	0.257	0.304	0.003	-0.007
				$R = -0.83$	0.90
				$p = 0.039$	0.015

Correlation significance level:  $p = 0.05$

The strength of the relation between the quantifiable impacts of urbanization and distance were examined by analyzing the correlation of their peak and mean stage range with distance (Table 4). Peak stage and mean stage range were obtained by computing the difference between the peak and mean stage values of the scenarios. The correlation results obtained were significant ( $p$  values below 0.05) and strong ( $R$  or correlation values above  $-0.8$  and  $+0.85$ ). For Scenarios 2 and 3 against Scenario 1, there was a strong negative correlation,  $-0.86$  and  $-0.83$ , respectively, between the increased of peak stage resulting from greater urbanization and distance. This implied that the increment of peak stage becomes less evident as distance increases further downstream as shown by the peak ranges of Points 'd/e' and 'e' (0.006 to 0.003 m only) that are located 3.25 and 5.8 km from the target areas. The peak range reduced from 0.26 m to an insignificant value of 0.003 m for Scenario 2 and 0.61 to 0.003 m for Scenario 3. The mean range had a strong positive correlation of 0.88 and 0.9 with the increase of distance for both scenarios against Scenario 1. This implied that mean range increases with distance from target areas. As discussed earlier, this is due to lower variation of stage levels between scenarios for simulation points located further downstream. In short, the correlation values indicate there was a strong

statistical relation that implied that the further a channel point is located from urbanizing areas, the lesser the impact of urbanization upon it. These correlations imply the impact of urbanization will be greater on the immediate downstream point such as Point 'c'. Point 'c' had a peak range that was 2.5 and 3.25 times higher than its downstream point, i.e. Point 'd' (located 250 m away) for Scenarios 2 and 3, respectively. As for Point 'e' which is located 5.05 km away, Point 'c' had a peak range that was 76 and 176 times higher. The implication above could be substantiated by analyzing the peak stage reduction rate of each scenario. Peak stage reduction rates (i.e.  $d^3y/dx^3$ , where 'y' is peak stage and 'x' is distance) were computed by extracting the third derivative of each scenario from their third order polynomial curves that have  $R^2$  values above 0.9 (Fig. 4). Third order polynomial curves were used because they gave a better fit than other curve fitting techniques. Scenario 3 had a higher peak stage reduction rate,  $-0.19$ , compared to Scenario 2,  $-0.13$ , and Scenario 1,  $-0.11$ . In other words, the reduction rates become negatively higher with greater urbanization. As a result, the peak stages virtually showed no distinction between scenarios as the simulation distance reaches 3.25 and 5.8 km marks although the initial peak stages at 0 km clearly showed the effect of urbanization. The effect of urbanization on peak stage whether it is resulting from 50% or 100% urbanization of the upper Rambai River paddy fields is greater on the immediate downstream point (Point 'c'). Further downstream, the impact of increasing urbanization was significantly lesser due to increasing peak reduction rates.

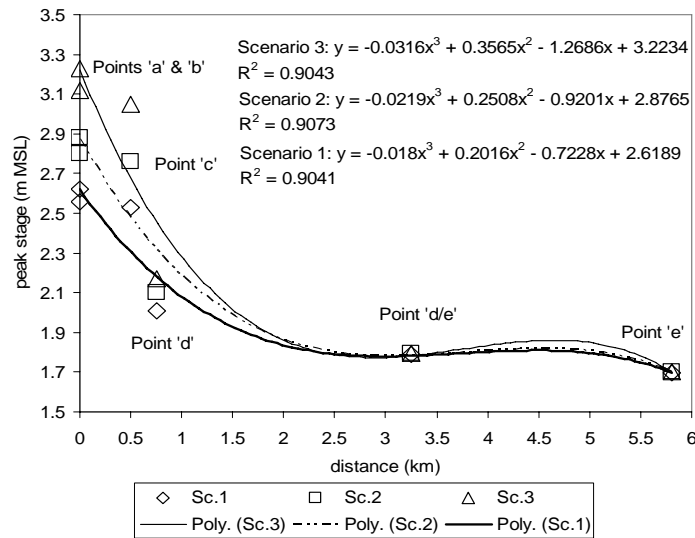


Figure 4: Peak stage reduction.



The effect of this relationship upon catchments located along the external channel was examined by computing and comparing their percentile increase of peak stages and flood levels (Tables 5 & 6). The paddy fields and villages of Permatang Rawa and Ara River received the highest increase of flood level, 9.6% to 10.8% for Scenario 2 and 21.9% to 27.6% for Scenario 3 compared to Scenario 1. As a result of reduced storage areas at Sites 1 and 2, their flood levels increased by 0.29 m in Scenario 1 to 0.71 m in Scenario 3. Sites 3 to 6 also received a significant increase of flood levels especially for Scenario 3, ranging from 0.21 m to 0.61 m. In socio-economic terms, Sites 3 to 6 would suffer the greatest impact of floods because they consist of densely built-up residential and commercial areas. Sites 7 to 11 generally do not receive any significant increase in flood level for Scenarios 2 and 3 except for Site 7 which is located immediately after Rambai River inlet.

Table 5: Peak stages and maximum flood depths of Scenarios 1, 2 and 3.

Sites	GL	ps-0	fd-0	ps-50	fd-50	ps-100	fd-100
1	1.80	2.59	0.79	2.87	1.07	3.30	1.50
2	1.80	2.63	0.83	2.93	1.13	3.34	1.54
3	1.88	2.56	0.68	2.80	0.92	3.12	1.24
4	1.60	2.12	0.52	2.22	0.62	2.33	0.73
5	1.88	2.62	0.74	2.88	1.00	3.23	1.35
6	2.00	2.14	0.14	2.26	0.26	2.37	0.37
7	0.90	1.98	1.08	2.09	1.19	2.17	1.27
8	1.67	1.84	0.17	1.86	0.19	1.88	0.21
9	0.88	1.14	0.26	1.14	0.26	1.14	0.26
10	0.88	1.23	0.35	1.23	0.35	1.23	0.35
11	1.51	1.97	0.46	1.97	0.46	1.97	0.46

Note: GL-ground level; ps- peak stage; fd-flood depth (in meters); ps-0 .... ps-100 and fd-0....fd-100 – peak stage and maximum flood depth at 0% of urbanization (Scenario 1 ) to 100% of urbanization (Scenario 3).

On the whole, sites located in the paddy fields (Sites 1 and 2) and the immediate downstream area (Sites 3 to 6) generally experience higher percentile increase of peak stage and flood level for Scenarios 2 and 3 (5.4% to 27.6% increment) compared to Sites 7 and 11 (0.25 to 9.5% increment) which are located 0.75 to 5.8 km downstream on the Rambai River floodplain. These differences in flood depth increments are the results of the attenuating effects of channel bank areas adjacent to Points 'a', 'b' and 'c' functioning as overflow storages, and the channel storage itself. However, as a result of receiving greater overflows, these storage areas will experience higher flood levels as shown in Table 5 (Sites 1 to 6). As mentioned earlier, these upstream storage areas could have caused a lesser upward migration of downstream peak stages shown in Figure 3. This could explain why there are strong negative correlations between peak stage range and distance for scenarios examined.

Table 6: Changes in flood depths.

Sites	Present land use	Sc. 1	Sc. 2 vs Sc. 1		Sc. 3 vs Sc. 1	
		fd	fd ch.	%	fd ch.	%
1	paddy field & village	0.79	0.28	10.78	0.71	27.56
2	paddy field & village	0.83	0.29	11.03	0.70	26.75
3	village	0.68	0.25	9.58	0.56	21.90
4	commercial area	0.52	0.11	4.96	0.21	9.97
5	built-up housing area	0.74	0.26	9.85	0.61	23.13
6	commercial area	0.14	0.12	5.42	0.23	10.74
7	built-up housing area	1.08	0.11	5.76	0.19	9.50
8	built-up housing area	1.17	0.02	1.14	0.04	2.12
9	built-up housing area	0.26	0.00	0.00	0.00	0.00
10	built-up housing area	0.35	0.00	0.00	0.00	0.00
11	plantation & village	0.46	0.01	0.25	0.01	0.36

Note: fd and fd ch. – flood depth and change in maximum flood depth in meters; Sc. 1- Scenario 1; Sc. 2- Scenario; Sc. 3- Scenario 3.

In short, the changes in peak stages at each of the sampling points indicated that the increase of peak stages and flows from Permatang Rawa and Ara River sub-basins due to urbanization and storage loss has a greater impact on

its immediate downstream channel section and its adjacent catchments than the floodplains further downstream floodplains.

#### 4. CONCLUSION

The effects of urbanization on hydrological systems have been well-documented in the hydrological literature. Urbanization decreases storage areas which results in shorter lag time and higher peak flows.<sup>3,5,6</sup> As a result, it produces larger and quicker floods.<sup>4,9</sup> Moreover, it increases the flood frequency of a given size and magnitude of a given flood.<sup>1</sup>

The simulated Scenarios 2 and 3 when compared to the present condition, Scenario 1, further exemplify what has been discussed in the literature concerning the hydrological impact of the loss of storage areas resulting from urbanization. The simulated results indicated that higher peak flows and higher stage could occur if the upstream paddy fields of Rambai River, Units 1, 159 and 160, were 50% and 100% urbanized. Nevertheless, their increment would not be proportional to the percentage of urbanization. The results also indicated that the remaining paddy fields and villages near the urbanized area and also the immediate downstream areas which consist of built-up residential and commercial areas would be significantly affected by floods. However, the results also indicate that areas located further downstream would not experience a significant increase of flood levels. In short, an increase in flood frequency and magnitude could be expected for the upper Rambai Valley in the future as concluded by an earlier research conducted in this area.<sup>14</sup>

Since runoff coefficients were used to relate rainfall-runoff rationally, there is a tendency of assuming that peak flow and stage would increase rationally with the proportionate increase of impervious area when the Rational Method was used for land use and drainage planning. It should be noted that this method is still widely used in some parts of the world including Malaysia.<sup>16,19,24</sup> For such planning purposes, this study showed that assumptions concerning future stage levels should not be made solely based on the proportionate increase of urban surfaces. Such assumptions could lead to costly overestimation or worse under designed system which is ineffective in preventing or mitigating floods. Furthermore, this study also implied that the hydrological impact of urbanization even though it may involve a significant portion of a river basin, e.g. Scenario 3 represents 8.5% increase (273 ha) of urban surface in Rambai River basin (3225 ha), it may be significant only to areas adjacent to those undergoing urbanization. Thus, careful examination has to be made on the transfer of impact downstream if the adjacent affected areas undergo certain mitigation measures.

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