Backwater Effect of Tidal Water Level Fluctuation and Riverine Discharge in An Idealized River

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Abstract. Rivers debouching into the sea are subjected to tidal variation at the river mouth. Tide-river interaction can cause variations in discharge by giving an additional gradient in water level which known as a backwater effect and somehow can cause serious flood event. The main purposes for this paper are to determine the effect of backwater on the river under steady flow and flood condition. Hydrodynamic model was believed has the capabilities to simulate the behaviour of tide and flood coming from the river upstream. Numerical simulation of backwater effect due to riverine discharge into the open sea shows that significant backwater effect can be observed landward up to the point where the channel bed rises above the mean sea level. Tidal effect dominates in this lower reaches, whereas riverine peak discharge tends only to increase the water level in the upper reaches. The simple, idealized tide-river model reproduces the hydraulic of low land river well and can be extended to investigate the full range of tide and river flow to generalize the effect for backwater prediction.

1. Introduction

Major flood events in Malaysia are frequently cited to be partially attributed to high tide when riverine outflow is hindered, causing widespread inundation of low land flood plain area. High-tide phenomenon always triggers flooding at Selangor coastal areas. In 2016, high tide phenomenon occurred over coastal areas in Selangor for five days with sea water levels up to 5.6 metres [1]. Two districts, namely Klang and Sabak Bernam, were classified as “red zone” or high-risk flood prone areas. In 2018, floods occurred in Klang again, making eleven victims from three families were evacuated to the Telok Pulai Community Hall in Klang [2]. High-tide flooding causing damage and bulky losses to the people. Coastal communities are believed suffer economically from frequent high-tide flooding and the impact is expected to worsen as sea level rise will continue [3].

Tide-river interaction can cause variations in water surface profile, giving an additional gradient which is known as backwater effect. It is a common occurrence at the downstream of a river near the river mouth. Failure of urban storm drainage system to take into consideration the increased tailwater level attributed to backwater phenomenon can lead to inadequate design that increases the occurrence of flood events. It is thus important to understand the dynamic behaviour of the process which is ubiquitous in lowland river system.

The combined effect of tide and river discharge is difficult to study using physical model. Recreating tidal effect in laboratory environment requires major pumping facility. In addition, proper scaling of the river length and water depth within the limited space of a basin can be challenging. Furthermore, accurate measurement of water surface difference is highly dependent on the accuracy of the instrument available. Hence, numerical simulation using an idealized river is a feasible alternative to provide insight
into the dynamic hydraulic behaviour of a river [4–5]. This contrasts simulation for specific river where the results obtained are unique to the particular river system. In this paper, we present the study of tidal effect on river water profile using numerical modelling, considering a simple, idealized river geometry.

2. Methodology

2.1. Model Setup

In this study, an idealized straight river section is considered [6]. The typical cross section as shown in Figure 1 comprises a rectangular main channel with a width of 300 m and a depth of 5 m at the river mouth, and decreases to 50 m wide and 2.5 m deep at the upstream limit. The floodplain on both side of the main channel has the same width at every point and at a slope of 1/100 towards the main channel. The river section profile variation from the river mouth to the upstream limit is described by a general parabolic function in the form of equation (1):

\[ y - H = a(x - L)^2 \]  

where

- \( x \) = longitudinal direction (m)
- \( y \) = lateral (or vertical) direction (m)
- \( L \) = maximum distance (m)
- \( H \) = maximum width (or elevation) (m)
- \( a \) = constant

Figure 1. Typical river cross section

The elevation of the river is assumed to vary from 0 m at the river mouth (CH 0) to 13 m at the upstream limit (CH 20), with a total length of 20 km, hence the resulting bed elevation is as shown in Figure 2, where the bed slope ranges from \( 3.25 \times 10^{-5} \) m/m at the downstream, to \( 1.235 \times 10^{-3} \) m/m at the upstream of the river. This represents a realistic mild-slope river such as observed in the Lower Klang River (LKR).

Using the same approach, the profile of the top of the main channel and the top of the flood plain is similarly determined. The top of flood bank is arbitrarily assigned to limit flood overflow within the flood bank. Figure 2 shows the longitudinal view of the idealized river model. The same parabolic function is also applied to the width of the main channel and the floodplain, hence giving the river plan view as shown in Figure 3. All the other sections in between are interpolated at equal intervals. The coefficient of contraction and expansion is assumed to be 0.1 and 0.3 respectively.
2.2. **Simulation Setup**

Hydrologic Engineering Center River Analysis System (HEC-RAS) is used in the present study. The software is known to be a robust hydraulic model which can be used to calculate water-surface profile and energy grade lines for steady and unsteady flow based on the solution of the energy equation. In the present investigation, one-dimensional computation is carried out assuming that flow in a typical wide river is dominated by flow in the longitudinal direction dominates with negligible lateral and secondary flow effect.

Simulations are performed for four (4) flow conditions: (i) steady river flow with normal depth at the river mouth, (ii) steady river flow with fixed river stage at the river mouth, (iii) steady river flow with tidal boundary condition, and (iv) unsteady flood flow with tidal boundary condition. For steady flow condition, a river regular discharge of 50 m$^3$/s and a high discharge of 115 m$^3$/s such as that observed in the Klang River Basin are considered. This high discharge condition is occurred during the monsoon seasons. For fixed river stage condition, the downstream water level is set to 5 m representing the mean sea level (MSL), a condition which typifies Lower Klang River (LKR). For steady flow with tide, the downstream boundary condition is a stage hydrograph which describes a semidiurnal tide. Tidal water
level fluctuation for a 14-day period from 24th Oct to 7th Nov 2018 at Port Klang with tidal range up to 2 m is adopted (Figure 4).

**Figure 4.** Tidal water level at the downstream

For unsteady flow simulation, a flood hydrograph is used for the upstream boundary condition. The discharge increases from a background value of 50 m$^3$/s to a peak of 115 m$^3$/s. The rise and fall of the peak discharge is assumed to follow an idealized triangular profile where the change is effected within the catchment time of concentration (Figure 5) calculated based on equation (2) [7]:

$$t_c = \frac{F_c L}{A^{1/10} S^{1/5}}$$

where

- $t_c$ = time of concentration (min)
- $F_c = 58.5$
- $A$ = catchment area (km$^2$)
- $S$ = slope channel (m/km)

**Figure 5.** Triangular flood hydrograph with a base flow of 50 m$^3$/s and peak of 115 m$^3$/s.
3. Results and Discussion

Figure 6 shows the flow profiles during regular river discharge of 50 m$^3$/s. Results show that a fixed downstream water level corresponding to the MSL (at 5 m elevation) causes significant backwater effect on the downstream-most river reaches. For a higher discharge rate of 115 m$^3$/s, a similar trend is observed (not shown). In both cases, the backwater effects are significant up to approximately 15 km inland, further which the effect may be treated as negligible. This corresponds to the point where the channel bed elevation rises above the MSL. Compared to the water depth under normal flow condition, the backwater effect at 12 km inland is 64% for $Q = 50$ m$^3$/s, but only 40% for $Q = 115$ m$^3$/s. Higher discharge shows lower backwater effect due to the high water level under normal flow condition.

![Figure 6. Steady flow profile during regular discharge ($Q = 50$ m$^3$/s)](image)

Next, a transient peak discharge of 115 m$^3$/s attributed to catchment flood flow was considered (see Figure 7). Examination the kinematic flood movement shows that flood peak takes approximately one hour to travel from the upstream boundary to the downstream of the computational domain in the absence of tidal signal. During the flood event, water level is observed to remain in the main channel only, i.e. there is no river bank overflow as shown in Figure 7.

![Figure 7. Unsteady flow condition during flood peak](image)

Figure 8 shows the results when this transient peak occurs in conjunction with spring high water and spring low water, respectively. Compared to the case of steady flow with tide only, additional increase
of water level attributed to the peak discharge is only significant at the upriver reaches further inland of CH 12. Water level is observed to rise by up to 0.6 m at the upstream limit, equivalent to 75% of the background river water level. Meanwhile at the lower reaches, water level variations are negligible, suggesting that the tidal effect is dominant. Hence, there is no main concern when peak flood coincides with spring low water condition.

**Figure 8.** Water surface profile with tidal effect under unsteady flow condition

The above results show that downriver backwater effect is entirely governed by high tidal water level. Simulation for steady background flow under the tidal signal in Figure 4 shows water level increases by up to 1.6 m at CH 14 (3.5%) during spring high water although there is no overflow. Downstream of CH 10, flood bank overflow occurs (Figure 9). At CH 8, water depth above the river bank measures 0.83 m, and overflow a distance of 51.7 m from the main channel (Figure 10). At the river mouth (CH 0), water depth above the river bank measures 1.8 m, and overflow a distance of 180 m. This shows that there is coastal flooding for the idealized channel section under the prevalent coastal climate condition considered.

**Figure 9.** Downstream flood bank overflow occurs during spring high water
Figure 10. Flood bank overflow at CH 8 (left) and CH 0 (right)

This study is a preliminary investigation of the combined effect of tide and flood discharge on an idealized river with rectangular main channel and sloping flood plain, where the section dimensions, i.e. width and depth, varies following a parabolic function. Results verified the occurrence of backwater effect due to riverine discharge into the sea water mass, which dominates the downriver reaches landward until the point where the channel bed rises above the mean sea level (MSL). During high water, flood peak causes increase of water level only at the upriver sections which are not subjected to tidal fluctuation. The HEC-RAS model assumes straight river centreline and 1D flow, which are applicable to a large wide river as considered in the present case, and the effect of channel roughness is not investigated.

4. Conclusion
The model is limited by the specific dimension applied. The results, however, can be normalized to generalize the backwater effect of identical river sections. A finite value for the slope of the flood plain towards the main channel is defined in this study to simulate realistic widening effect of flood overflow. However, instead of a fixed value applied as in the present case, the value could be varied to cover a range of possible values. In fact, the flood plain slope governs the magnitude of backwater effect at the downriver lower reaches. The effect of both tidal amplitude and river discharge can be better understood if combinations of a range of values are examined. Furthermore, the two factors can be aggregated as a ratio of tidal mass flow rate (in m$^3$/m) to the river discharge [8]. The model also can be further improved by considering the meandering effect of a typical low land river, where secondary flow may be important such that there is a water surface gradient in the lateral direction.

5. References

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