# EFFECT OF BED SHAPE ON SUBSURFACE FLOW STRUCURES AND WATER BUDGET IN A RIVER WITH ALTERNATE SANDBAR

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## 1. Introduction

Recently, sandbar in a river has been considered as a source of purification of surface water and also recognized as a habitat for some micro-species like benthos and hypohreo those live in the substrate near surface water. These arguments are true when surface water interacts with subsurface water in a river with alternate sandbar, especially during low flow conditions. This interaction, being treated as horizontal 2-D problem, is evaluated by solving two governing equations. In this paper, the effects of different bed shapes on surface water profile and then on the subsurface flow structures and water budget is discussed by 1-D surface and 2-D subsurface flow model results.

## 2. Governing Equations

**Surface flow model** 1D surface flow model is employed to get the longitudinal distribution of surface water elevation in a river with alternate sandbar as shown in **Fig.1**. The bed shape is given by the Eq.1 as follows:

$$Z_b = D - (x - \frac{L}{2})I + a\sin\frac{2\pi(x - \frac{L}{2} + \frac{\lambda}{4})}{\lambda}\cos\frac{\pi y}{B} \tag{1}$$

Where, $D$ is the average thickness of the permeable layer at $0.5L$; $L$ $(= 1.5\lambda)$ is the total length of the river reach; $B$ is the width of the river; $\lambda$ is the sandbar wavelength (=3m); $a$ is the sandbar's amplitude, $I$ is the average bed slope; $x$ and $y$ are the co-ordinates. Finite volume methods with collocate grid and time developing scheme is followed for numerical solutions of the following governing equations:

$$\text{Continuity Equation: } B\frac{\partial H}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{2}$$

$$\text{Momentum equation: } \frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}(QU) = -gA\frac{\partial H}{\partial x} - \frac{n^2 g Q^2}{R^{4/3}A} \tag{3}$$

Where, $H$ = surface water level from impermeable layer, $Q$ = surface flow discharge, $A$ = cross-sectional area of flow, $U$ = flow velocity, $g$ = acceleration due to gravity, $n$ = Manning's co-efficient and $R$ = hydraulic radius.

**Subsurface flow model** A steady-state 2-D depth averaged model is applied based on Dupuit-Forchheimer assumption (Bouwer, 1978) given that the permeable layer is uniform and isotropic (hydraulic conductivity, $k$ is constant) and bottom impermeable layer is horizontal and boundary condition is the surface water elevation at the edge. Finite difference method with staggered grid is used for numerical solutions. The governing equation is:

$$\frac{k}{2}\left[\frac{\partial^2 h^2}{\partial x^2} + \frac{\partial^2 h^2}{\partial y^2}\right] = 0 \tag{4}$$

Where, $h$ is subsurface water depth from impermeable layer.

## 3. Results and Discussion

**Subsurface flow structures:** Subsurface flow structures at the upstream part of sandbar are greatly influenced by the steep gradient of surface water at immediate downstream of the riffles (**Fig.2**) and the effect is more pronounced in case of higher amplitude with steep slope case (**Fig.2b**). If we compare among the cases in **Fig.3(a)** or **Fig.3(b)**, we see that contour interval at both part of the sandbar is high for low water level (LWL). The contour intervals in these figures also show that the lateral gradient between surface and subsurface water at the upstream part is high for LWL and very high for higher bed amplitude case (Case-c, **Fig.3**). For LWL, the inflow part is wider than that for high water level (HWL) and as a result the total flux becomes higher.

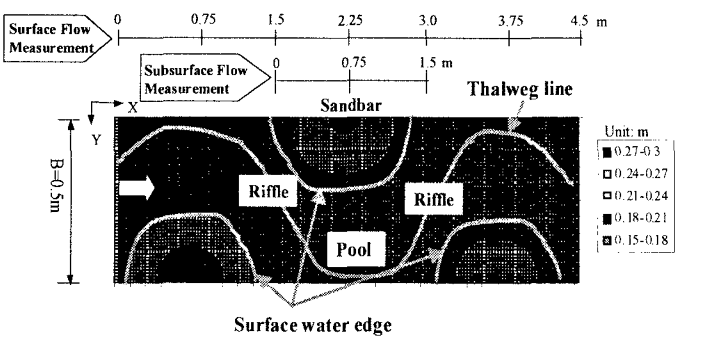



**Fig.1** Surface flow model set-up

**Subsurface water budget:** Subsurface water budget along the surface water's edge with sandbar can be evaluated by inspecting the value of residual subsurface water flux, $Q_x'$ (Pl. see **Fig.4**) as expressed by Eq.5.

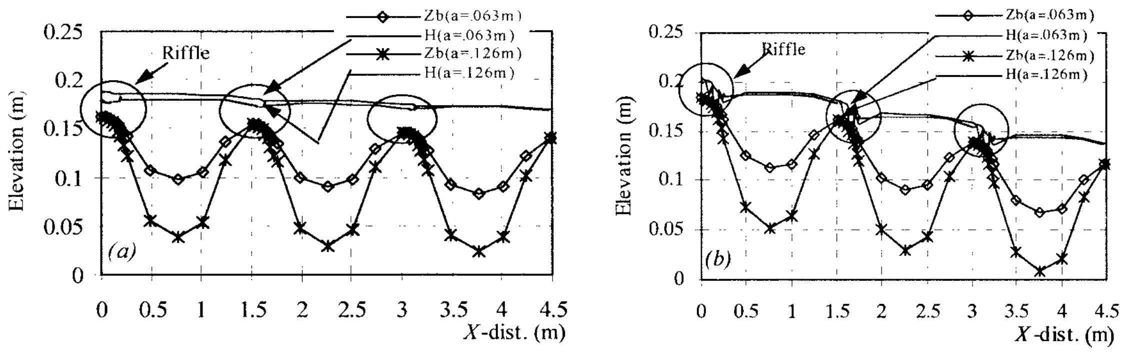
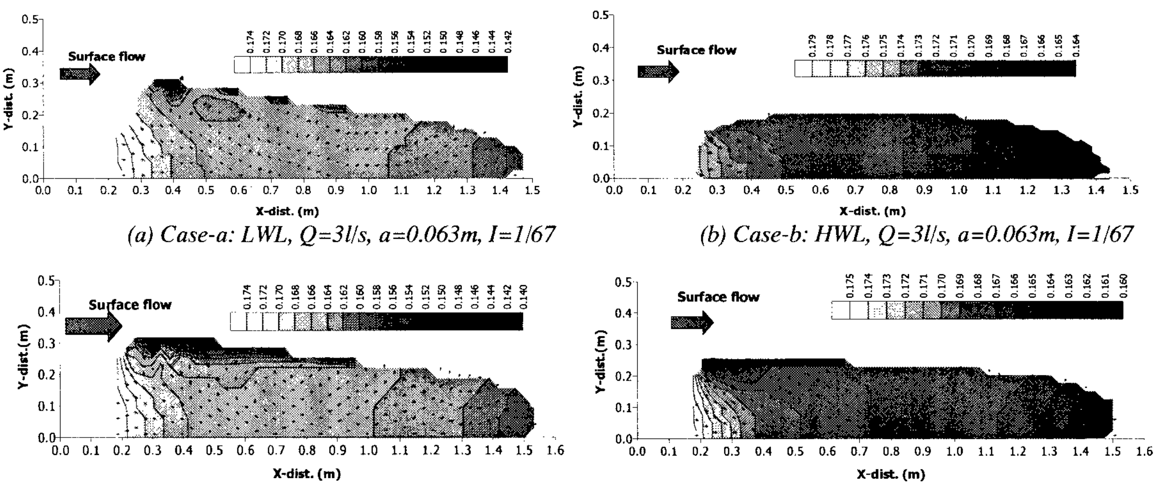


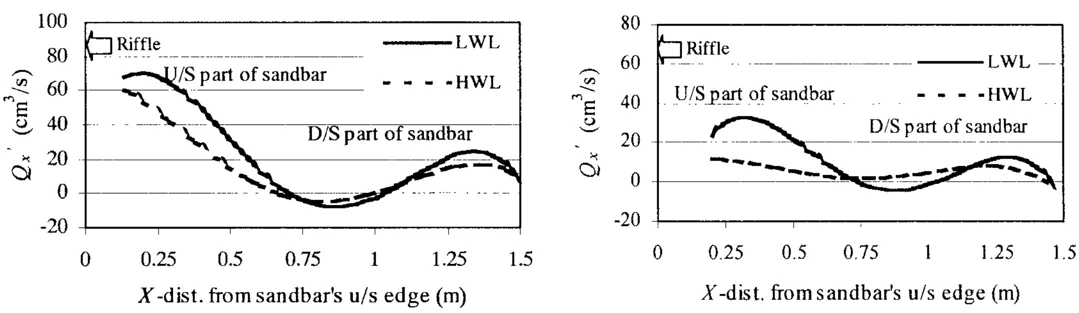

**Fig.2** $Z_b$ and $H$ along thalweg line: *(a) Q=3 l/s, I=1/200, (b) Q=3 l/s, I=1/67*




*(a) Case-a: LWL, Q=3l/s, a=0.063m, I=1/67* *(b) Case-b: HWL, Q=3l/s, a=0.063m, I=1/67*

*(c) Case-c: LWL, Q=3l/s, a=0.126m, I=1/67* *(d) Case-d: HWL, Q=3l/s, a=0.126m, I=1/67*

**Fig.3** 2-D distribution of subsurface water level and Darcy vector




*(a) Q=3l/s, a=0.126m, I=1/67* *(b) Q=3l/s, a=0.063m, I=1/67*

**Fig.4** $Q_x'$ from upstream to downstream of sandbar

$$Q_x' = \int_{y=0}^{y=y_{end(x)}} \bar{q}_x(x,y)dy \, , \bar{q}_x(x,y) = -kh(x,y)\frac{dh}{dx} \qquad (5)$$

Where, $Q_x'(x)$=subsurface water flux under sandbar at the cross-section $x = x$, $\bar{q}_x(x,y)$ is flux per unit width, $y_{end(x)}$ is the transverse distance (at $x = x$) from $y = 0$ (side wall) to surface water's edge. Here, **Fig.4** shows that at the upstream part of sandbar, inflow flux is higher at immediate downstream of the riffle where the surface water gradient is higher and also magnitude is higher for LWL conditions in compare to HWL conditions. It is observed that the high amplitude is posed to generate higher inflow flux at the upstream part (**Fig.4a**).

## 4. Conclusions

The simulation results revealed that the subsurface flow structures and the water budget are greatly influenced by the gradient of surface water profile, which are the functions of bed shape and hydraulic conditions. The steep surface water gradient on the riffles generates diverging trend in the subsurface flow at the upstream part of sandbar and this trend is stronger for higher bed shape parameters. The flow rate is found to be higher at the upstream part of sandbar than that at the downstream part.

## References

1. Bouwer, H.: (1978) *Groundwater Hydrology*, McGraw-Hill, Newyork.