Application of 1-D soil erosion model for Ishikari River: the case of 1975, 1981 flood events

Hokkaido University Student Member ○Sanit Wongsa

Hokkaido University Member of JSCE Yasuyuki Shimizu

Hokkaido University Student Member Masashi Iwai

1. Objectives

A hydrodynamic model of 1-D soil erosion is developed in this paper. A new concept is presented for predicting slope runoff associated with soil erosion by raindrop impact and tractive shear force exerted by overland flow of a river basin/catchment scale. The model consists of 4 sub-modules, such as, channel flow used a CIP scheme, and slope runoff, channel sediment transport, and slope soil erosion used an upwind scheme. Performance of the proposed numerical model was applied to simulate flood events in 1975, and 1981 to test the hypothesis that eroded soil materials from upstream mountainous slope/river would also be an importance component of sediment yields in Ishikari River basin.

2. Governing equations

Channel flow and sediment model:

The set of continuity and momentum equations of 1-dimensional unsteady flow can be expressed as

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial X}=q_L \quad (1) \qquad \frac{\partial Q}{\partial t}+\frac{\partial\left(Q^2/A\right)}{\partial X}+gA\left(\frac{\partial H}{\partial X}+S_f\right)=\frac{q_L Q}{gA^2} \quad (2)$$

where A = cross-sectional area of flow; Q = discharge; q_L = lateral flowrate; g = acceleration due to gravity; H = water surface elevation (H = η+h); η = bed elevation; h = water depth; S_f = friction slope; and t, X = time and channel-flow direction coordinate, respectively.

The continuity equation of depth average suspended sediment and volumetric fractional of bed material can be obtained from (3), (4) as

$$\frac{\partial}{\partial t}\left(<c_i>h\right)+\frac{1}{B}\frac{\partial\left(Q<c_i>\right)}{\partial X}=q_{sui}-w_{f_i}c_{bi}+\frac{q_L c_{BLi}}{B} \quad (3) \qquad \delta\frac{\partial p_i}{\partial t}+p_i^*\frac{\partial \eta}{\partial X}+\frac{1}{1-\lambda}\left[\frac{1}{B}\frac{\partial\left(q_{Bi}B\right)}{\partial X}+q_{sui}-w_{f_i}c_{bi}+\frac{q_L c_{BLi}}{B}\right]=0 \quad (4)$$

where $<c_i>$ = depth average suspended sediment concentration; B = channel width; q_{sui} = pickup rate; w_{fi} = fall velocity; p_i = volumetric fractional of bed material; q_{Bi} = bedload; and λ = void ratio (λ = 0.4).

The time dependent change of bed elevation calculated by the following continuity of bed material transport.

$$\frac{\partial \eta}{\partial t}+\frac{1}{1-\lambda}\left[\frac{1}{B}\frac{\partial \sum_i\left(q_{Bi}B\right)}{\partial X}+\sum_i\left(q_{sui}-w_{f_i}c_{bi}\right)+\frac{\sum_i\left(q_L c_{BLi}\right)}{B}\right]=0 \quad (5)$$

where $\sum_i$ = summation of bed material transport load.

Slope runoff and erosion model:

A slope runoff with interflow model is governed by the kinematic wave equation, which can be express as

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=r_e \quad (6) \qquad q=\begin{cases} kS_0 h/\gamma & for \quad 0<h<\gamma D \\ \alpha\left(h-\gamma D\right)^m+kS_0 h/\gamma & for \quad h\geq \gamma D \end{cases} \quad (7)$$

where h = water depth; q = unit discharge; r_e = effective rainfall intensity; k = infiltration rate; γ = void ratio; D = layer thickness; α = $\sqrt{S_0}/n$; S_0 = bed slope; n = Manning's roughness coefficient; m = 5/3; and x = slope-flow direction coordinate.

The mass conservation of the sediment and volumetric fractional of bed material can be given by (8), (9) as

$$\frac{\partial\left(c_i h\right)}{\partial t}+\frac{1}{B}\frac{\partial\left(c_i Q\right)}{\partial x}=D_{ri}+D_{fi}-D_{di} \quad (8) \qquad \delta\frac{\partial p_i}{\partial t}+\frac{1}{1-\lambda}\left[\frac{1}{B}\frac{\partial\left(q_{Bi}B\right)}{\partial x}+D_{ri}+D_{fi}-D_{di}\right]=0 \quad (9)$$

where c_i = sediment concentration; D_{ri} = rainfall detachment rate; D_{fi} = overland flow detachment rate; and D_{di} = deposition rate.

Keywords CIP method, kinematic wave, slope erosion, sediment yield

Contact Hokkaido University, Graduate School of Engineering, Kita-13, Nishi-8, Kita-ku, Sapporo 060-8628 TEL001-706-6198

3. Numerical Results

The Ishikari River basin was discretized into 29 sub-basins (Fig. 1). Initial conditions were setting for discharge at most upstream end, normal depth and zero depth in channel and slope, respectively. The eroded soil was transported down the slope into channel with no addition soil from channel banks. Calculated conditions are as follows, k = 0.015 m s^{-1}, γ = 0.18, D = 0.5 m, Δt = 2.0 s, ΔX = 1000 m, Δx = 200 m, and n = 0.02, 0.2 for channel and slope, respectively. The time series of simulated discharge, bedload, suspended load, and total load at Akahira and Ishikari Bridge gauge stations are shown in Fig. 2 and 3. The sediment yields of eroded soil, bedload, suspended load, and total load from slope for simulated period of 40.3 m^3, 40.4, 12.8 and 53.2 (x10^4) m^3, comparing with the values of 211.0 (x10^4) m^3, which determined form measured during July to August, 1981. It was founded that the overall magnitudes of the flow and sediment discharges are simulated well, and that a reasonably good accuracy.

4. Conclusions

In this study, a hydrodynamic model 1-D channel and slope runoff with sediment erosion were developed. Ishikari river basin with 1975, and 1981 flood events were used to verify the proposed model. The calculated results indicate that this proposed model satisfactorily predicted the flow and sediment discharge with good agreement. However, the model performance should be extended to simulate for long terms and impacted of change of land use problems, by considering mainly the scale of months to a year.

Acknowledgements

The authors wish to thank The Hitachi Scholarship Foundation for financially supported the first author. We are also indebted to Hokkaido Development Bureau and Hokkaido River Disaster Prevention Research Center who provided the field data.

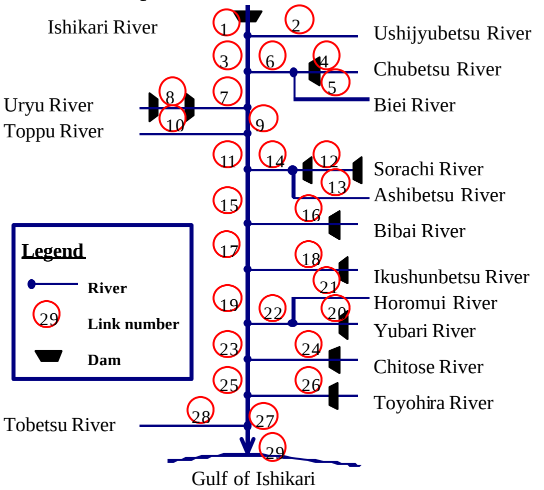

Fig.1. Schematic of Ishikari River model.

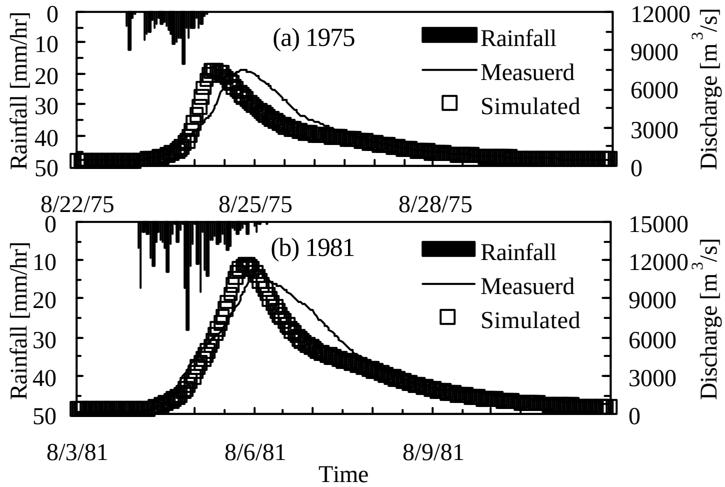

Fig.2. Comparison of discharges at Ishikari Bridge gauge station.

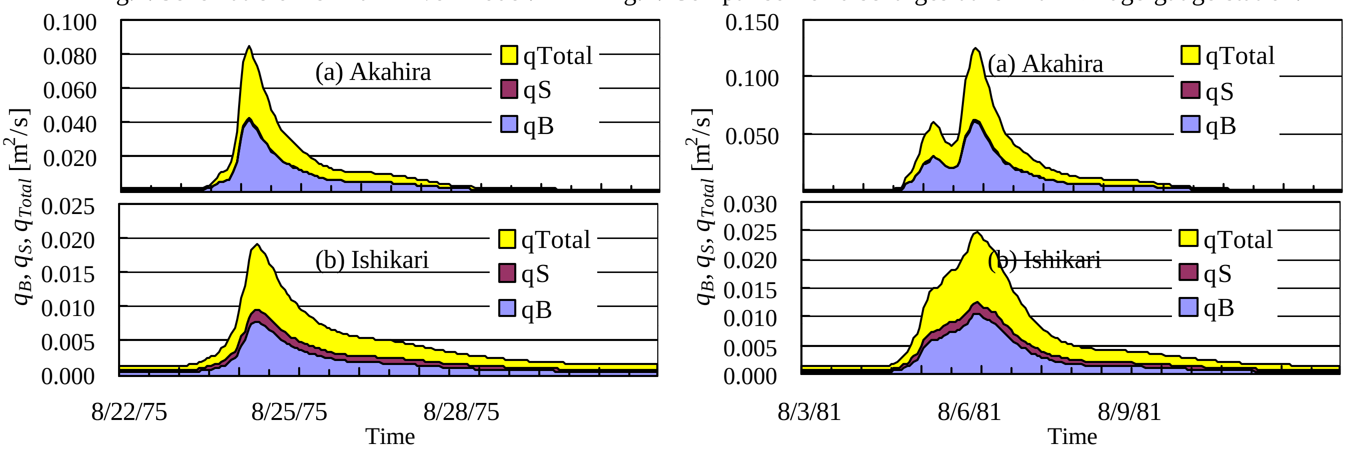

Fig.3. Simulated results of bedload, suspended load and total load at (a) Akahira and (b) Ishikari Bridge gauge stations.

References

- Sanit, W., Shimizu, Y. and Nakui T. (2001) Application of 1- and 2-dimensional coupled of hydrodynamic model and kinematic runoff model for Kushiro wetland. In *Proc. of the Third Int. Symp. on Environmental Hydraulics*, Arizona, 5-8 December.
- Sanit, W. and Shimizu, Y. (2002) 1-D Slope Runoff and Sediment Erosion Modeling for Alluvial River. In *Proc. of the Fifth Int. Conf. on Hydro. & Engrs.*, Warsaw, Poland, 18-21 September. (in press)