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Prediction of erosion and deposition in a mountainous basin

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Abstract A model for identifying areas of erosion and deposition over a mountainous basin was developed based on the mass balance principle. The program consists of three steps: (a) estimation of soil erosion; (b) determination of flow amount and direction; and (c) estimation of mass balance. Soil erosion was estimated with the USLE. A single-direction flow and a multi-direction flow algorithm were applied to estimate slope length (*L*). The Maximum Downhill Slope Method (MDS) and the Neighborhood Method (NBH) were used to estimate the slope degree (*S*). Sediment transport resulting from eroded soil was estimated using Ferro's (1998) and Swift's (2000) sediment delivery ratio (SDR). The flow direction was determined using a geographic information system (GIS) program. The model was validated by comparing the predicted sediment yields for three basins with measured data. Ferro's SDR Method combined with the MDS Method produced the best results for mountainous basins in Korea.

Key words sediment delivery ratio; sediment deposition; sediment erosion

INTODUCTION

Soil erosion in mountainous areas not only causes the destruction of plants, but also nonpoint-source pollution within a basin. The environmental impacts of soil erosion, whether the result of anthropogenic activities or natural disasters (e.g. urbanization, wildfires) could be minimized by the introduction of best management practices. The appropriate location(s) for the introduction of such practices can be identified through the use of accurate soil erosion models.

To achieve this goal, a two-dimensional distributed model for estimating sediment yield and deposition in mountainous basins was developed and tested. The validated model can then be used to predict the amount and destination of the eroded soil under various hydrological conditions. Further, predictions of the distribution of nonpoint-sources of sediment could be used to identify sites where appropriate countermeasures should be applied in an effort to reduce subsequent environmental impacts.

BASIC ASSUMPTIONS AND THEORY DEVELOPMENT

The topographical variations in a basin exercise control over such factors as the soil yields, the sediment transport efficiency, and the sediment mass balance. Soil yields for each cell were estimated using the Universal Soil Loss Equation (USLE). Sediment transport efficiency for each cell was estimated using SDR methods.

Certain basic assumptions were made for this study. They include: (a) that a basin consists of equal rectangular cells that are fairly standard in a grid-based digital elevation model (DEM)—all the rectangular cells in a basin were treated as small basins; (b) that erosion and deposition in each cell have an isotropic characteristic; (c) steady-state conditions, to permit the determination of a mass balance and soil yields; and (d) that all the erosion and deposition within the individual cells will occur contemporaneously. Based on the foregoing assumptions, the final model required completion of three steps: (i) estimation of soil erosion in each cell; (ii) determination of the flow volume; and (iii) determination of the direction of flow from each cell, and a mass balance for each cell.

Soil erosion was estimated with the USLE. The application of the USLE, with a single-flow algorithm, is commonly employed for the quantitative estimation of soil yields in many areas of Korea (Son, 2001). However, it is well known that a single-flow algorithm is insufficient to simulate actual flow phenomena, especially in mountainous regions (Son, 2001). Hence, in this study, the effects of non-uniform slopes on soil erosion were considered in estimating the slope length (*L*) and the degree of slope (*S*). To that end, a distributed model was used in conjunction with a multi-directional algorithm. Previous work indicated that this approach was likely to produce better estimates for *L* and *S* (Son, 2003). Further, the Maximum Downhill Slope (MDS) and the Nighbourhood Slope (NBH) methods were used to estimate *S*. Sediment transport from each cell was estimated using Ferro's (1998) and Swift's (2000) sediment delivery ratio (SDR) methods. Flow direction was determined using a GIS program. Lastly, an algorithm based on the mass balance principle of soil yield was employed to estimate the amount of erosion and deposition occurring in each cell. The most appropriate method for estimating the SDR was determined by comparing various predictions with actual measurements made at the outlet of each sub-basin (cell).

ALGORITHM DEVELOPMENT

The continuity equation for sediments for an individual cell i can be described as:

$$\Delta S_i = [(I_i^+ + I_i^-)/2 - (Q_i^+ + Q_i^-)/2]\ \Delta t \tag{1}$$

where ΔS_i is the stored sediments in cell i during Δt; I_i^+, I_i^- are sediment inflows at the beginning and end of the routing period; and Q_i^+, Q_i^- are sediment outflows at the beginning and end of the routing period.

The steady-state assumption for cell i during Δt yields $I_i^+ = I_i^- = I_i$, $Q_i^+ = Q_i^- = Q_i$. Therefore, equation (1) was simplified as either:

$$\Delta S_i = I_i \Delta \mathrm{t} - Q_i \Delta \tag{2}$$

$$\Delta S_i = YI_i - YO_i \tag{3}$$

where YI_i is the inflow sediment for cell i; and YO_i the outflow sediment for cell i.

The difference between the sediment inflow (YI_i) and the outflow (YO_i) represents sediment storage in a cell (ΔS_i). The outflow sediment amount (YO_i) at cell i is determined from the sediment yields at cell i (Y_i), and the sediment delivery ratio (SDR_i).

1	0	0
0	4	0
0	0	9

Fig. 1 Sediment yields (Y_i).

0.5	0	0
0	0.1	0
0	0	0.5

Fig. 2 Sediment delivery ratio (DR_i).

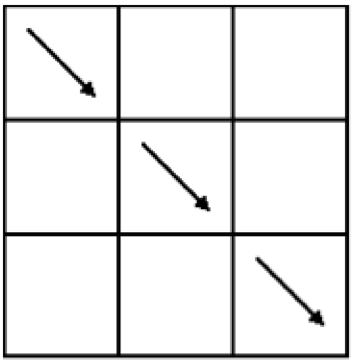

Fig. 3 Sediment transportation direction.

$$Y_i \times DR_i = YO_i \qquad (4)$$

The concept of the developed model was verified with a simplified imaginary basin consisting of nine cells. Figure 1 shows the imaginary basin and the number in each cell represents sediment yield (Y_i) and Fig. 2 shows the sediment delivery ratios (SDR_i). The simulated direction of sediment transportation for each cell is shown in Fig. 3.

Sediment outflow (YO_i) for each cell (Fig. 4) was estimated by multiplying Y_i by SDR_i. Accumulated sediment for each cell along the flow path is shown in Fig. 5. Sediment inflow (YI_i) can be estimated using equation (5) (see Fig. 6).

0.5	0	0
0	0.4	0
0	0	4.5

Fig. 4 Sediment outflow (YO_i).

0	0	0
0	0.9	0
0	0	5.4

Fig. 5 Accumulated sediment outflow ($acc.YO_i$).

−0.5	0	0
0	0.5	0
0	0	0.9

Fig. 6 Sediment inflow from equation (5).

$$acc.YO_i - YO_i = YI_i \quad (5)$$

The "–0.5" shown in Fig. 6 was corrected to "0" (Fig. 7) by considering the boundary conditions. Sediment storage (ΔY_i) is the difference between the sediment inflow (YI_i) and outflow (YO_i) as shown in Fig. 8.

$$YI_i - YO_i = \Delta Y_i \quad (6)$$

Negative (–) values in Fig. 8 indicate erosion in the cell whereas, positive (+) values indicate deposition in the cell. The algorithm flow diagram is shown in Fig. 9.

0	0	0
0	0.5	0
0	0	0.9

Fig. 7 Real sediment inflow (YI_i).

−0.5	0	0
0	0.1	0
0	0	−3.6

Fig. 8 Sediment storage (ΔY_i).

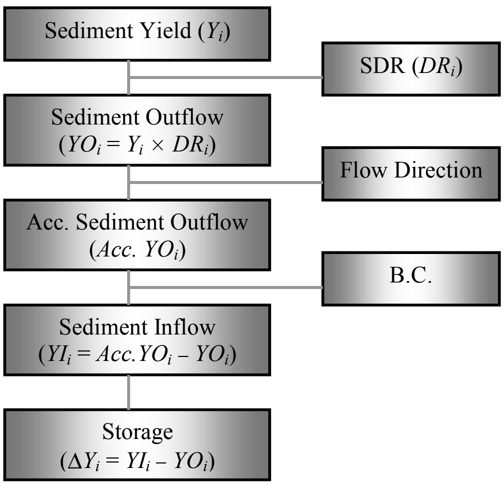

Fig. 9 Algorithm for sediment outflow estimation.

APPLICATION FOR COMPARISONS

The applicability of all the methods and the model described above, was evaluated by comparing predicted against measured values of soil yield determined at the outlet of the basins. The model was applied to three agricultural reservoirs in Korea. Figures 10–12 display the estimated results using the SDR suggested by Ferro & Minacapilli (1995), and Ferro *et al.* (1998). The SDR equation of Ferro *et al.* (1998) was applied in Method 1-1, by assuming that eroded material will reach the nearest watercourse.

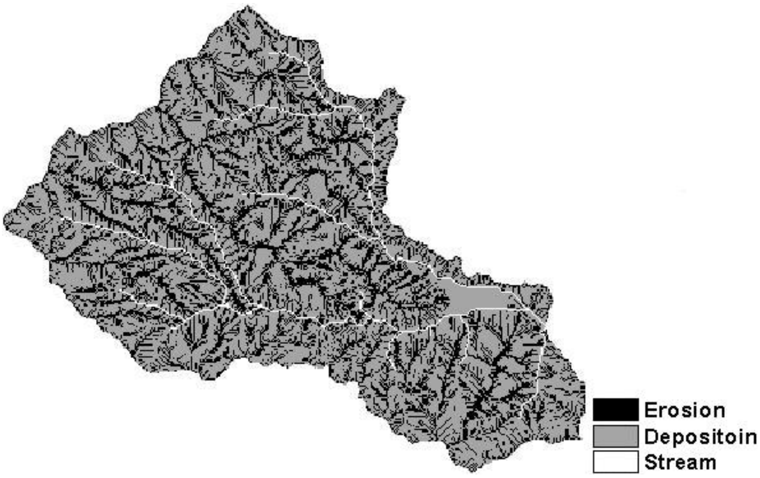

Fig. 10 Erosion and deposition distribution with Method 1-1.

Fig. 11 Predicted erosion quantity with Method 1-1 (0.85~0.0 t year^{-1} cell^{-1}).

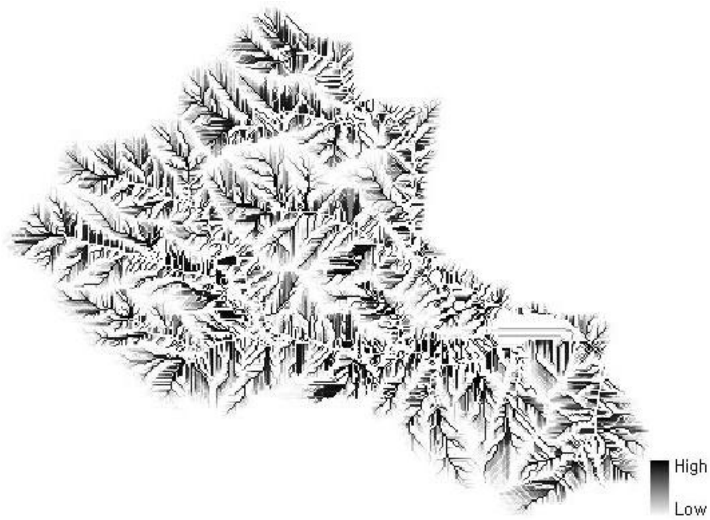

Fig. 12 Predicted deposition quantity with Method 1-1 (10.43~0.0 t year^{-1} cell^{-1}).

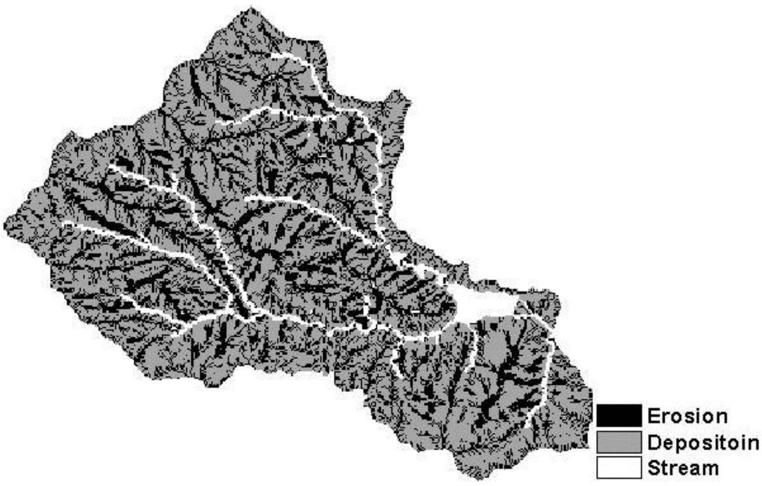

Fig. 13 Erosion and deposition distribution with Method 2.

Fig. 14 Predicted erosion quantity with Method 2 (0.46~0.0 t $year^{-1}$ $cell^{-1}$).

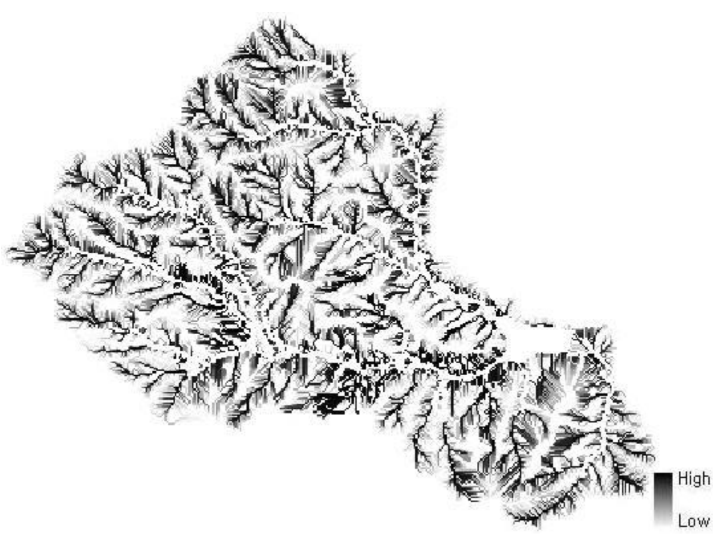

Fig. 15 Predicted deposition quantity with Method 2 (5.81~0.0 t $year^{-1}$ $cell^{-1}$).

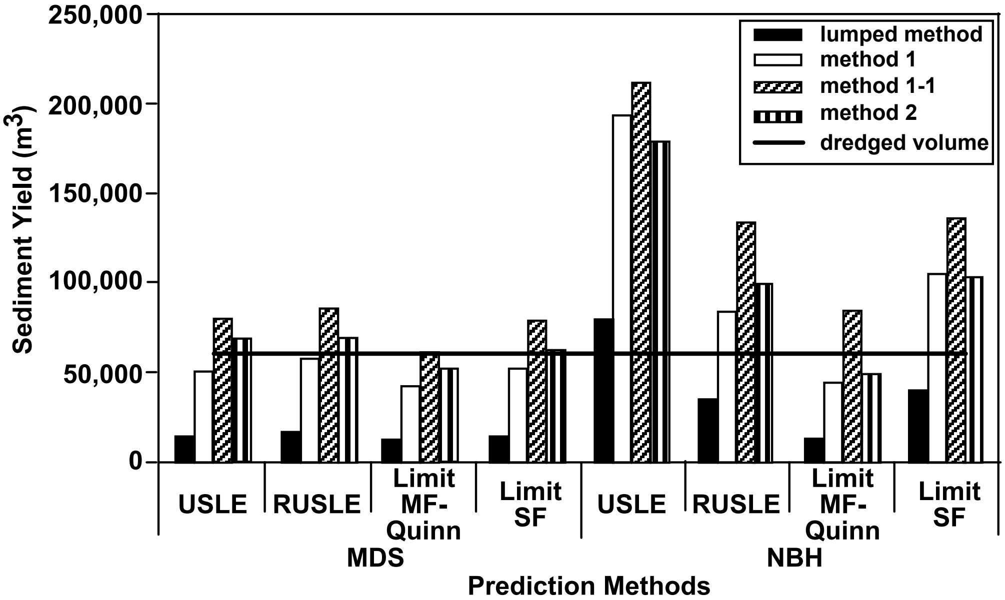

Fig. 16 Soil yield comparisons for Songjun agricultural reservoir.

Figures 13–15 show the estimated results with the SDR suggested by Swift (2000). Swift's (2000) SDR equation was applied in Method 2. Comparisons of soil yield for Songjun Reservoir (Fig. 16) indicate that Method 1-l, in conjunction with the MDS method, produced the best result based on dredging records for the reservoir.

CONCLUSIONS

A distributed model for quantifying erosion and deposition over a mountainous basin was developed based on the sediment mass balance principle. The model was validated by comparing the predicted sediment yields for three basins with measured data. Ferro's SDR method used in conjunction with the MDS method appears to generate the best results for mountainous basins in Korea.

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REFERENCES

Elliot, W. J., Hall, D. E. & Scheele, D. L. (2000) *WEPP Interface for Disturbed Forest and Range Runoff, Erosion and Sediment Delivery*, USDA Forest Service Rocky Mountain Research Station and San Dimas Technology and Development Center

Ferro, V. & Minacapilli, M. (1995) Sediment delivery processes at basin scale. *Hydrol. Sci. J.* **40**(6), 703–717

Ferro, V., Porto, P. & Tusa, G. (1998) Testing a distributed approach for modelling sediment delivery. *Hydrol. Sci. J.* **43**(3), 425–442.

Hickey, R, Smith, A. & Jankowski, P. (1994) Slope length calculations from a DEM within ARC/INFO GRID. *Computers, Environment and Urban Systems* **18**(5), 365–380.

Quinn. P., Beven, K., Chevaller, P. & Planchon, O. (1991). The prediction of hillslope flow paths for distributed hydrological modelling using Digital Terrain Models. *Hydrol. Processes* **5**, 59–79.

Son, K. I. (2003). Evaluation of LS parameters in USLE using GIS. *J. Korean Soc. Civil Engnrs* **23**(4B), 281–287.

Son, K. I. (2001). Applicability examination of the RUSLE sediment yield prediction equations in Korea. *J. Korea Water Resour. Assoc.* **34**(3), 199–207.

Swift, L.W., Jr (2000). *Equation to dissipate sediment from a grid cell downslope.* USDA Forest Service, USA

Wischmeier, W. H. & Smith, D. D. (1965). Predicting rainfall erosion losses from cropland East of the Rocky Mountains. US Dept Agric. Agricultural Research Service*. Agricultural Handbook no. 282.*