A Study on Sediment Yield for Small Watersheds

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Introduction

Estimates of watershed sediment yield are required for solution of a number of problems. Design of dams and reservoirs, transport of pollutants, design of soil conservation practices, design of debris basins, depletion of reservoirs, lakes and wetlands, determination of the effects of basin management, and cost evaluation of a water project are some of the examples. Sediment is a pollutant or a carrier of pollutants such as radioactive material, pesticides, and nutrients. Increased awareness of environmental quality and the desire to control non-point source pollution have significantly increased the need to estimate sediment yield.

Williams(1978) extended the concept of the instantaneous unit hydrograph (IUH), h, to determine sediment discharge from an agricultural watershed, using the IUSG, hs. In the spirit of the instantaneous unit graph he defined the IUSG as the distribution of sediment from an instantaneous burst of rainfall producing one unit of runoff. The IUSG is the product of the IUH and the sediment concentration distribution (SCD). Sediment concentration of the IUSG is assumed to vary with the effective rainfall volume. A sediment routing function, using travel time and sediment particle size, was used to determine the SCD. The concept of IUSG has also been employed by Singh et al. (1982), Chen and Kuo (1984), and Srivastava et al. (1984) among others.

Watershed sediment yield systems are, in general, nonlinear and time-variant. Their parameters vary in time and space, and when they are assumed constant, they are so only by assumption. The errors in a sediment yield model may arise due to inadequacy of the model itself, parameter uncertainty, errors in the data used for parameter estimation, and inadequate understanding of the watershed sediment yield process due, in part, to randomness. The error in the prediction of sediment yield due to the uncertainty caused by the physical process , the model, and the input data can be reduced if Kalman filter is incorporated in a sediment yield model.

The Kalman filter determines the state vector of the process model using two ways: (1) the observation data and (2) the model parameters. Todini(1978) analyzed the former method and Hino(1974) analyzed the latter. In this study, sediment yield is predicted by the IUSG model coupled with Kalman filter to improve sediment yield prediction. The state vector is composed of the IUSG by the IUSG model and the sediment yield is estimated by the IUSG model using Kalman filter. Thus, reducing the physical uncertainty of the watershed sediment yield system this study aims to develop a more accurate sediment yield model for sediment yield prediction.

Kalman filter

The Kalman filter is a state estimation algorithm of a state-space model and optimally represents the system state of a deterministic or a stochastic model which has uncertainties in observed data, initial and boundary conditions, and parameters. The process of filtering is a mathematical operation which utilizes the past data or measurement of a dynamic system in order to make more accurate statements about the present, future or past state of the system than could have been made using information from a single direct measurement. The Kalman filter algorithm is constituted by three components: system model, measurement model, and Kalman filter.

Instantaneous Unit Sediment Graph (IUSG)

Following Williams(1978) the IUSG can be defined as the distribution of sediment from an instantaneous burst of rainfall producing one unit of runoff and is considered to be the product of the IUH and the sediment concentration distribution:

IUSG using Kalman filter

The IUSG was used in this study as the fundamental model for predicting sediment yield.

System model

The state space model using Kalman filter is constituted by the IUSG, which is then allowed to vary in time. The state vectors X(k) are ESY(k), the estimated sediment yield at time k and U(k), the ordinate of IUSG at time k

Measurement model

The observation variable applicable to the IUSG is sediment yield, Y.

Study basin

A small upland watershed, W-5, a part of Pigeon Roost basin located near Oxford, Marshall County, Mississippi, was selected for testing of the IUSG using Kalman filter. It has an area of approximately 4.04 km2, is 1288 m long and 128.8 m wide.

Conclusions

The following conclusions can be drawn from this study. (1) The IUSG using Kalman filter yields better results than the IUSG without the filter in terms of error indices and computed sediment yield graphs. (2) The state vectors, the IUSG and sediment yield vary appropriately in time. (3) The Kalman gain for the IUSG and the sediment yield is estimated and filtering enables improved sediment yield. (4) The Kalman gain, GK1, for estimated sediment yield, ESY, varies little and the little variation reflects that ESY corresponds to the observed sediment yield well. (5) The large variation of the Kalman gain, GK2, for the IUSG reflects that the filtering for IUSG works well.

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