Hydrologic Analysis of Hawaii Watersheds for Flood Control and Water Quality Management

Problem and Research Objectives

The establishment of the rainfall-runoff relationship of a watershed is an important and difficult problem in applied hydrology. The rainfall-runoff relationships of Hawai‘i watersheds are even more difficult to establish than most because Hawai‘i watersheds tend to have steep slopes, small drainage areas, and a high infiltration rate. Currently the simple *rational formula* is used for urban drainage design in Hawai‘i and the more sophisticated *unit-hydrograph method* is used for the design of large flood-control facilities.

The unit-hydrograph method is based on linear systems theory (Dooge 1973). The system impulse response function of a linear system describes the overall system characteristics which affect the input-output relationship. The determination of the system response function of a particular system is called system identification. By the unit-hydrograph method a watershed is taken as a linear system. Its input function is effective rainfall, its output function is direct runoff, and its system response function is called instantaneous unit hydrograph (IUH), which is the direct runoff generated by the watershed system when it receive an input of unit-pulse-effective rainfall. After the IUH of a watershed is identified, direct runoff generated by future rainstorms in the watershed can be calculated by a convolution integration of IUH and rainfall input.

Similarly for waste-loading simulation, the impulse-response function can be called the instantaneous pollutograph (IPG), which is the temporal variation of pollutant concentration at the watershed outlet generated by the watershed system when it receives an input of unit-pulse-effective rainfall. The waste loading at the watershed outlet can then be readily calculated as a product of direct runoff and pollutant concentration.

The principal objectives of this research were to 1) demonstrate the applicability of a linear-systems approach for flood and water-quality analysis for Hawaiian watersheds and 2) develop techniques for deriving IUH and IPG.

Methodology

The modern unit-hydrograph method, the most popular analytical tool for flood hydrograph analysis, can be formulated based on linear systems theory. By this method direct runoff produced by a rain storm over a watershed system can be calculated by a convolution integration of effective rainfall and instantaneous unit hydrograph (IUH). Direct runoff or system input is the measured stream flow minus groundwater contribution or base flow. System output or effective rainfall is the rate of rainfall after subtracting the rate of infiltration and other “losses.” System impulse response function, or IUH for a linear watershed system, is the direct runoff produced by a watershed when it receives a unit-instantaneous-effective rainfall.

The linear systems approach has been successfully used in watershed hydrology to relate rainfall to runoff (Liu and Brutsaert 1978). This type of approach has also been used recently in river-water-quality analysis (Liu and Neill 2002) and in chemical transport in soils (Liu 1988). In this project the linear systems approach is also applied to watershed water-quality analysis to simulate waste loadings generated by a watershed receiving heavy storm.

Following the linear systems approach, storm runoff from a watershed at any time can be calculated by a simple convolution of the instantaneous unit hydrograph (IUH) and the effective rainfall. The IUH of a particular watershed is usually derived by performing an inverse operation based on one set of historical rainfall-runoff data. For watersheds that have no historical rainfall-runoff data, a method of synthetic IUH or "grey method" (Liu 1988) can be used. Using the grey method the linear systems model of a watershed rainfall-waste loading can be formulated as:

$$Y(t) = \int_0^t g(\tau)\, f(t-\tau)\, d\tau$$

Where *Y(t)* = the system output or contaminant concentration
g(t) = the system input or effective rainfall
f (t) = IPG in terms of a particular probability density functions.

Principal Findings and Significance

During the project period, the linear systems model of sediment transport as shown in the equation above was tested based on data collected in Mānoa Watershed during a rainstorm of March 14, 2009. In this case the system input is derived based on the available sediment over the watershed prior to the rainstorm and the effective rainfall; the system output is the total suspended solids (TSS) concentration at the watershed outlet.

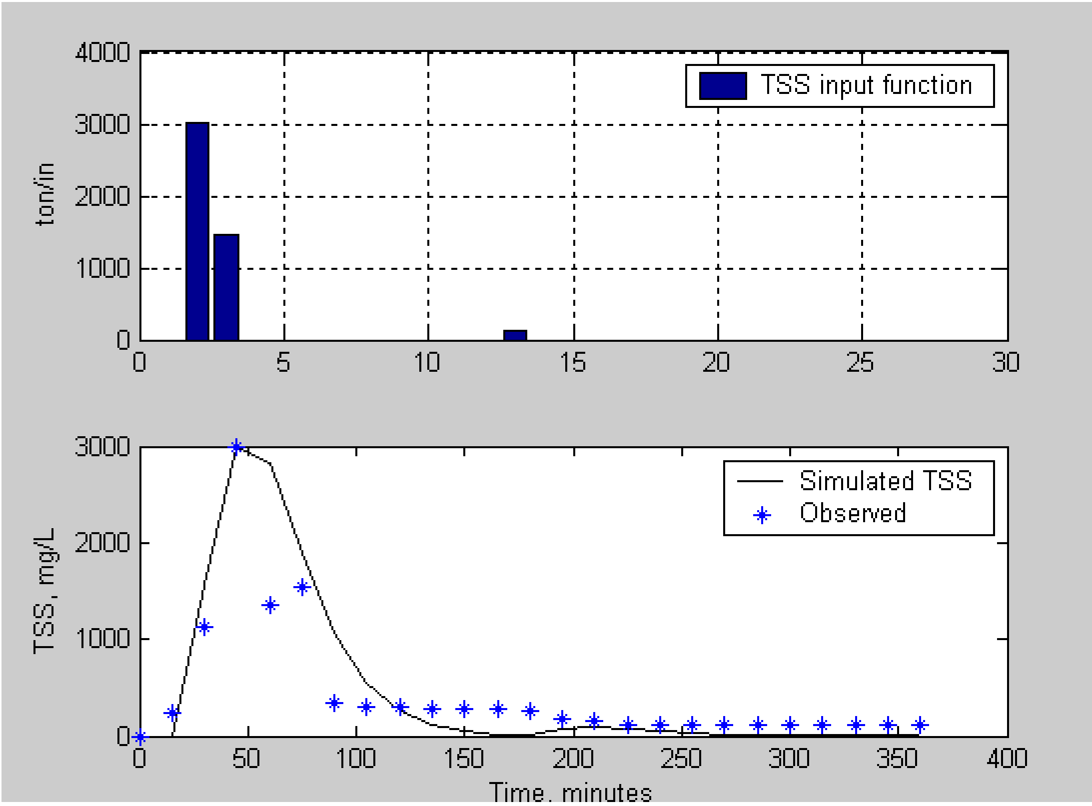

Figure 1. Simulated and Observed TSS loadings from Mānoa Watershed after a storm on March 14, 2009.

Publications Cited in the Synopsis

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