Report as of FY2007 for 2006HI144B: "Hydrologic Analysis of Hawaii Watersheds for Flood Control and Water Quality Management"

Publications

Project 2006HI144B has resulted in no reported publications as of FY2007.

Report Follows

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 Hawaii watersheds are even more difficult to establish because local watersheds have steep slopes, small drainage area, and high infiltration rate. Currently, the simple *rational formula* is used for urban drainage design in Hawaii, while the more sophisticated *unit hydrograph method* is used for the design of large flood-control facilities.

The unit hydrograph method is based on the linear systems theory. 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 and its system response function is called the instantaneous unit hydrograph (IUH). Its input function is effective rainfall and its output function is direct runoff. After the IUH of a watershed is identified, runoff generated by future rainstorms in the watershed can be calculated by a convolution integration of IUH and rainfall input. Therefore, the problem of establishing the rainfall-runoff relationship of a watershed becomes the problem of system identification or the derivation of IUH.

The principal objective of this research is to develop techniques for deriving the IUH of a watershed. These techniques will then be used for rainfall-runoff analysis of Hawaii watersheds relative to flood control and water quality management.

Methodology

The linear systems approach has been successfully used in watershed hydrology to relate rainfall to runoff. This type of approach has also been used recently in river water quality analysis and in chemical transport in soils. Following the linear systems approach, storm runoff from a watershed at any time can be calculated by a simple convolution of the 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 data, the synthetic IUH method is used.

Using a linear systems approach, a watershed rainfall-runoff model can be expressed as a convolution integral:

$$Q(t) = \int_0^t X(\tau)h(t-\tau)d\tau \qquad (1)$$

where $Q(t)$ is the system output function, or direct runoff generated from the watershed; $X(\tau)$ is system input function, or effective rainfall; and $h(t-\tau)$ is the system impulse response function, or instantaneous unit hydrograph.

Similarly, by using a linear systems approach, a watershed transport model can be expressed as

$$C(t) = \int_0^t W(\tau)g(t-\tau)d\tau \qquad (2)$$

where $C(t)$ is the output function, $W(\tau)$ is the pollutant input function, and $g(t-\tau)$ is the system impulse response function, or pollutograph.

The impulse response function of a linear system model describes the overall system behavior. The success of system modeling depends largely on how accurately and efficiently the impulse response function can be evaluated. In this research, the gray-box approach of system identification is used, such that the pollutograph of tropical watershed transport systems can be evaluated based on watershed parameters such as size, roughness, slope, soils, and imperviousness. These parameters can be easily obtained from a geographic information system.

Principal Findings and Significance

In this research, the gray-box approach of system identification is used, and an IUH, $h(t)$, takes the general form of a gamma distribution function:

$$h(t) = \frac{1}{\Gamma(N)} \frac{A}{K} \left(\frac{t}{K}\right)^{N-1} \exp\left(\frac{-t}{K}\right) \quad (3)$$

The system identification for any given watershed is used to estimate values of two parameters, or N and K, in Equation (3). These parameters are related to the peak discharge (Q_p) and time to peak (t_p) in an IUH by the following equations:

$$Q_p = \frac{1}{\Gamma(N)} \frac{A}{t_p 12} (N-1)^N \exp(1-N) \quad (4)$$

$$t_p = (N-1)\, K \quad (5)$$

This study uses historical rainfall-runoff data collected at nine watersheds on Oahu. The watershed areas vary between 303 hectares and 11,399 hectares (Figure 1).

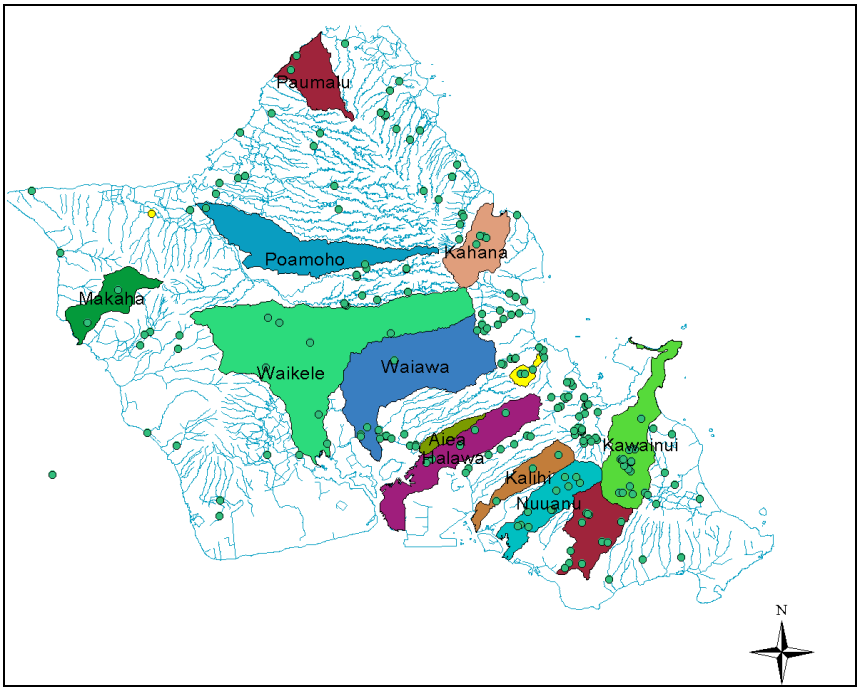

Figure 1. Watershed areas on Oahu selected for model development and testing

The IUH parameters N and K (or Q_p and t_p) were determined, based on historical rainfall and runoff data, as shown in Table 1.

Table 1. Parameters of the Instantaneous Unit Hydrographs of Selected Hawaii Watersheds

Watershed	Area (ha)	N	K	T_p (min)	Q_p (cfs)
Puekele	303	2.73	43.00	74.44	307
Makaha	589	1.77	117.20	90.55	314
Kalihi	653	2.33	42.56	56.64	407
Kahana	548	1.35	109.00	38.42	727
Waiahole	985	2.30	57.13	57.13	837
Halawa	1,175	1.30	52.00	15.00	2,034
Manoa	1,279	2.06	29.67	31.38	2,807
Waimea	3,159	3.77	48.00	133.00	2,332
Waikele	11,399	2.87	41.22	77.10	11,985

The IUH of the Wahiawa reservoir station can then be obtained as follows:

$$\text{IUH} = 3{,}557.13\left(\frac{t}{12.16}\right)^{2.5775} \exp\left(\frac{\Delta t}{12.16}\right) \qquad (6)$$

The IUHs derived by this study and by another researcher (I-Pai Wu, 1969, Hydrograph Study and Peak Discharge Determination of Hawaiian Small Watersheds: Island of Oahu, Technical Report No. 30, Water Resources Research Center, University of Hawaii, Honolulu) were applied in a modeling analysis to predict the runoff generated a storm on October 24-25, 2005. Modeling results are shown in Figure 2.

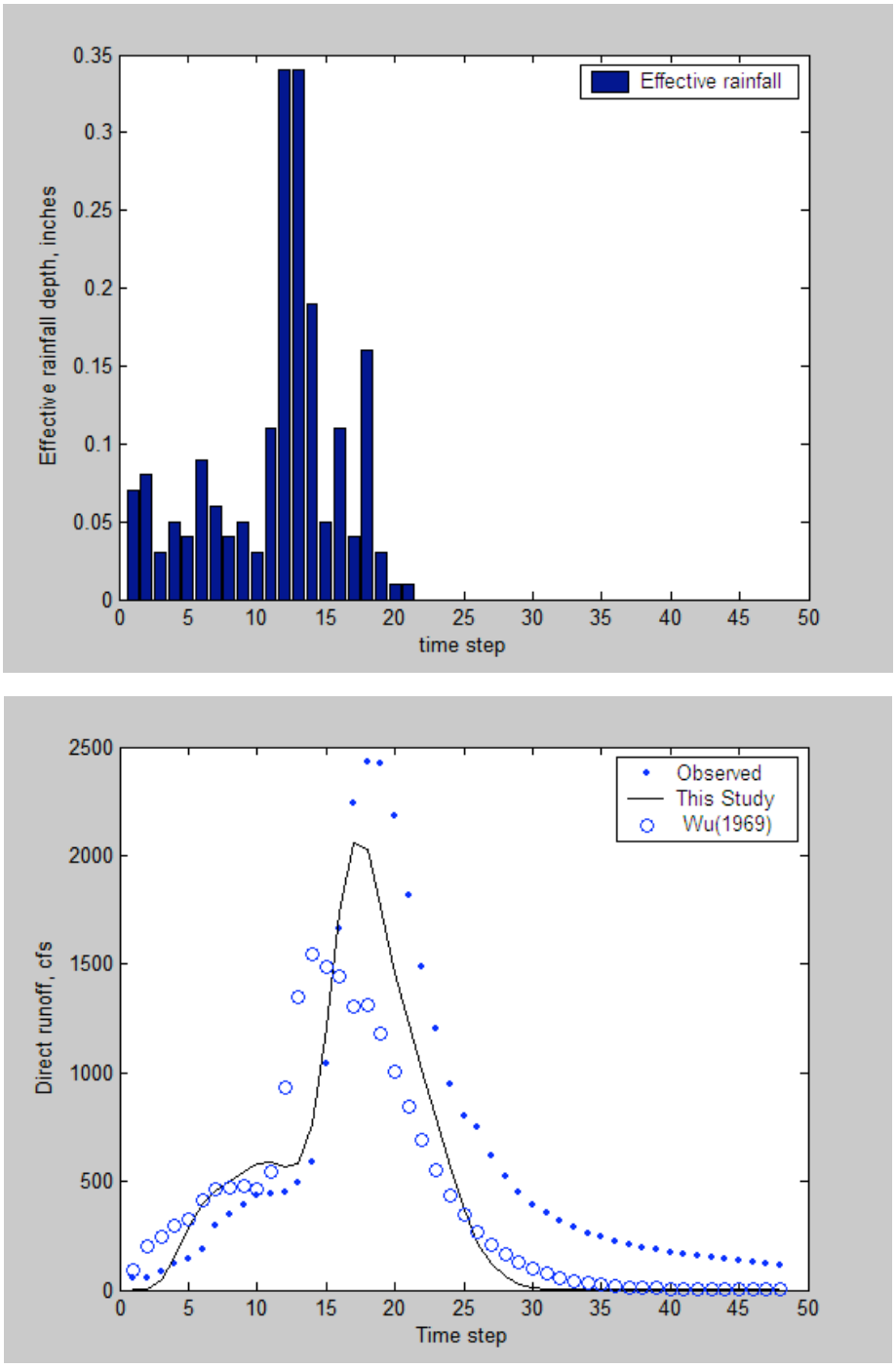

Figure 2. Prediction of storm runoff of Wahiawa Stream at USGS gaging station 10268000, October 29-30, 2005

Methods derived from this project will be used by a different project to conduct a survey and modeling analysis of Highway MS4 storm runoff on Oahu. In addition, a workshop to train the technical staff of city and state agencies engaged in storm water quality control is planned. A journal paper, entitled "Infiltration and Effective Rainfall in Flood Hydrograph Analysis of Hawaiian watershed" is in preparation (to be submitted by the end of summer). Two additional journal papers are contemplated.