Development of the San Joaquin County Hydrology Manual

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Abstract

A hydrology manual was prepared for the County of San Joaquin, California for the determination of storm runoff quantities for the design of flood management facilities, floodplain analysis, and drainage system design. Runoff is computed from rainfall for specific frequencies and duration. Appropriate loss rate procedures were developed based on land use and soil types. Runoff for small subbasins is computed using the Rational Method. For areas above one square mile in area, unit hydrograph calculations are used to compute runoff. Streamflow routing procedures were defined, and methods for analysis of flow-through and flow-by detention basins were developed. Due to the uncertainty in establishing an accurate value for the peak discharge associated with a specified frequency of a flood the parameters in the manual were chosen to provide an 85% confidence level for the flood discharges.

Introduction

The San Joaquin County Department of Public Works (1995) hydrology manual provides computational techniques and criteria for the estimation of storm runoff volume and time distribution of runoff or the peak discharge. These discharges are used for the analysis and design of stormwater management facilities for the areas within the county administered by the County Department of Public Works. In a significant sense the manual is intended to provide policy standards and guidelines for the county. It is important that the results from application of the manual procedures be consistent and fair, be scientifically defensible and dependable, be reliable and reproducible when applied by different users, and be relatively simple and easy to use. The procedures used should provide a reasonable "standard of care."

Relatively simple procedures have been found to give accurate estimation of discharges for design of project components for flood management projects at the county level. For small areas (less than one square mile) the Rational Method has been found to provide a good estimation of the peak discharge. For larger areas unit hydrograph procedures provide accurate determination of the runoff hydrograph. The most important factor associated with rainfall-runoff modeling is rainfall. The rainfall in this manual is based on the design storm concept which uses historical rainfall data to develop hypothetical design storms of various durations and frequencies for the calculation of runoff. Effective rainfall is determined by calculating time-dependent losses and subtracting the losses from the gross rainfall. Watershed losses are

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considered to be depression storage, interception, and infiltration. The two watershed loss components of initial abstraction and infiltration are considered in this manual.

Unit hydrographs are determined from dimensionless S-graphs appropriate to the type of watershed (i.e., urban, valley, foothill, etc.) being analyzed. Base flows are not significant for San Joaquin County streams, and base flow effects are incorporated in the unit hydrograph response. Streamflow routing is used where routing may affect the runoff hydrograph. Reservoir routing is used to analyze the effects of detention basins on reducing peak flood discharges.

Rainfall

Two forms of rainfall data for use with the San Joaquin County Hydrology Manual were developed. For hydrograph development a design storm is used. The parameters defining the design storm are storm duration, point rainfall depth, areal depth adjustment, storm intensity and time distribution of the rainfall. Rainfall intensity-duration-frequency curves were developed for Rational Method calculations. The data base for the rainfall for the manual was developed from historical records of rainfall within San Joaquin County and at appropriate nearby rainfall stations. Records for twenty-one rainfall gages within the county and seven gages in adjacent counties were used. Only five of these gages had rainfall data for durations of less than 24 hours. These gages had incremental rainfall values for durations as small as 5 minutes.

Rainfall for specified frequency and duration is calculated from the average maximum daily rainfall. The daily rainfall value is determined from the mean annual rainfall. The data are arranged into a pattern to form a design storm for hydrograph calculations. Tables of intensity-duration-frequency values for Rational Method applications were also prepared. The development of design storm procedures for San Joaquin County is described in more detail by DeVries and Hromadka (1994).

Loss Rate Computations

The two watershed loss components of initial abstraction and infiltration are related to the hydrologic soil groups in the subarea being analyzed, soil cover and condition, and extent of watershed development.

Hydrologic Soil Groups—The major factor affecting loss rates is the nature of the soil itself, including the soil surface characteristics, the soil's ability to convey water to subsurface layers, and the storage capacity of the soil. Soils are classified into the commonly-used four hydrologic soil groups as defined by the US Soil Conservation Service. These soil groups are Group A (low runoff potential), B (soil with moderate infiltration rates), C (soil having slow infiltration rates), D (high runoff potential). Detailed soil survey information from the Soil Conservation Service was used to prepare maps of hydrologic soil groups. This information was also digitized into a GIS layer for used with a computer-based hydrologic model of the county.

Soil Cover and Condition—Specific vegetation types and the condition of the cover (poor, fair, or good) are used to select a SCS Curve Number (CN) for calculation of loss rate, initial abstraction, and storm runoff yield.

Watershed Development Conditions—The usual assumption for watershed runoff calculation is that ultimate development of the watershed exists, because it is highly probable to occur within the expected life of most stormwater management projects. Long-range development plans were reviewed and future land use conditions assumed in these master plans was used for the loss rate computations.

Rational Method Calculations

The Rational Method is widely used throughout the U. S. to compute peak runoff from rainfall. In this approach the rainfall is defined by an Intensity-Duration-Frequency (IDF) relationship. The IDF relation is supplied as an equation or in tabular form. The runoff coefficient **C** used with the Rational Method is based on vegetation, cover density, infiltration capacity of the soil, and slope of the drainage area. The manual provides a confluence analysis procedure for estimating the peak flow by the rational method at the junction of two or more stream channels. The equations used for the confluence analysis assume that the catchment peak flow rates are only portions of larger hydrographic events. In the confluence analysis procedure the Rational Method is used to estimate peak flow by adjusting the catchment area to give a more realistic estimate of the contributing catchment area based on the critical duration of rainfall.

The Rational Formula, $Q = CIA$, is used to compute the peak discharge (Q) in cfs. **C** is a runoff coefficient, **I** is rainfall intensity in in./hr, and **A** is the drainage area in acres. The runoff coefficient **C** is assumed to be a function of the impervious and pervious area fractions, the infiltration rates for the pervious areas, and the effect of watershed detention. When the rainfall intensity **I** is greater than the area-averaged infiltration rate for tributary pervious areas (F_p) the runoff coefficient is computed from

$$C = 0.90[a_i + a_p(I - F_p)/I].$$

Otherwise, $C = 0.90a_i$. In these equations a_i is the ratio of impervious area to total area and a_p is the ratio of pervious area to total area ($a_p = 1 - a_i$). The proportion factor 0.90 is a calibration constant determined by an average fit between the Rational Method and peak discharges computed by the unit hydrograph method (Hromadka 1995).

Unit Hydrograph Calculations

Unit hydrographs are determined from dimensionless S-graphs that are representative of the type of watershed being analyzed. Individual S-graphs are used for valley, foothill, or mountain watersheds. S-graphs also may reflect the urbanization of the watershed, so that the watershed may be represented by a "Valley-Developed" S-graph or by a "Valley-Undeveloped" S-graph. Combinations of S-graph types can also be used for the computation of the unit hydrograph. For example, a watershed may be 30 percent "Foothill-Undeveloped" and 70 percent "Valley-Developed".

The dimensionless distribution graph (or dimensionless S-graph) is a form of a unit hydrograph whose ordinates are expressed in terms of percent of ultimate discharge and the time at which these discharges occur are fractions of the "basin lag." ***Lag*** for a watershed is the time (in hours) from the beginning of a continuous series of unit period effective rainfall to the instant when the rate of the watershed runoff equals 50 percent of the ultimate rate of the resulting runoff. The ultimate discharge **K** in cfs for the distribution graph is given by the following equation

$$K = 645\ A/T$$

where **A** is the drainage area in square miles, and **T** is the unit hydrograph time period in hours.

Determination of Lag—The ***lag*** is a parameter that relates time relationships of the hydrograph to physical characteristics of the watershed. When the lags determined from summation hydrographs for several gaged watershed are correlated to the hydrologic characteristics of other watersheds, an empirical relationship can be determined. This relationship can then be used to determine the lag for drainage areas for which the hydrologic characteristics can be determined, but for which distribution graphs are not available because of inadequate hydrologic data. Lag times determined from calibration in San Joaquin County and in other California counties have shown that lag is related to the time of concentration ($\mathbf{T_c}$) used in Rational Method analyses. For the definition of ***lag*** used here the relationship between ***lag*** and time of concentration is

$$lag = 0.8\ T_c$$

Because the Rational Method time of concentration is an important parameter for unit hydrograph analysis determination, a good deal of care must be taken in its use, and the San Joaquin County hydrology manual provides procedures for calculation of $\mathbf{T_c}$ that also take into account the return frequency of the event being modeled. For example, a 2-year storm $\mathbf{T_c}$ value will be longer in duration than a 100-year storm $\mathbf{T_c}$. For most basins $\mathbf{T_c}$ is computed as the sum of the $\mathbf{T_c}$ values for the Rational Method initial subarea $\mathbf{T_c}$'s plus subsequent reach hydraulic travel time values.

Due to the uncertainty in establishing an accurate value for the peak discharge associated with a specified frequency of a flood the rainfall and loss rate parameters in the manual were chosen to provide an 85% confidence level for the flood discharges. Using this procedure the agency can be confident that on a regional basis only 15% of the design discharges will be "too small." In contrast, using the expected value (*i.e.*, average fit to the flood flow frequency curve) to determine the design discharges guarantees that 50% of computed design discharges will be greater than the computed value and 50% will be smaller. This philosophy is similar to that used in Orange County (Nestlinger 1990) and for other Southern California county hydrology manuals.

Design Storm Patterns

The design storm pattern is based on a single synthetic 24-hr critical storm pattern that includes peak rainfall intensities from 5 minutes up to 24 hours. The storm pattern is shown in Figure 1. For small watersheds (usually less than 5 square miles) only the peak 3-hour period of the storm is used.

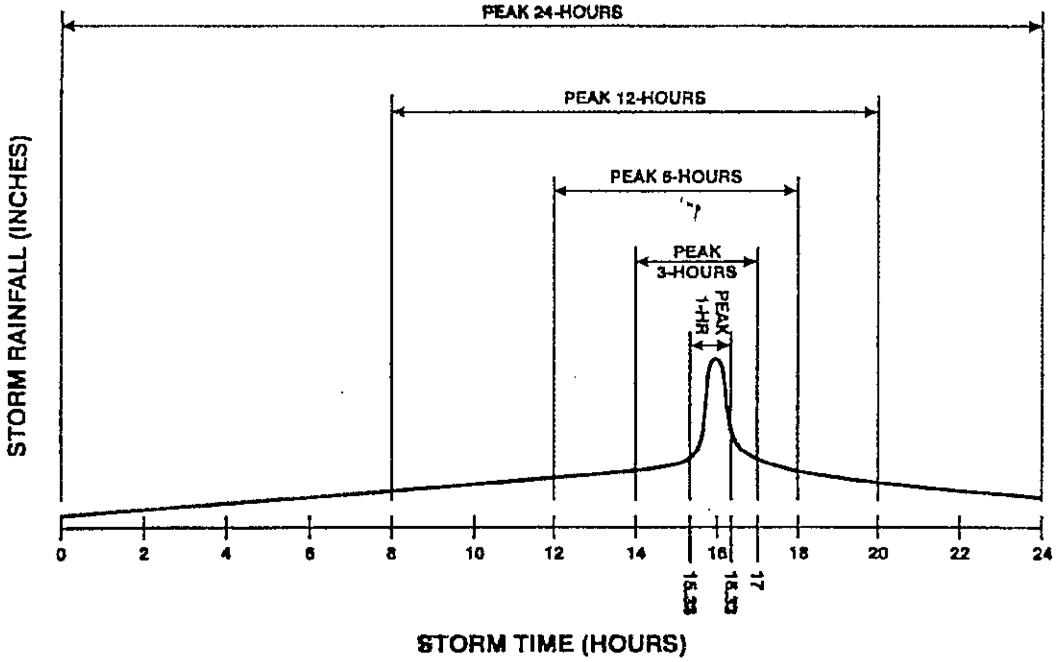

Figure 1. 24-hour Design Storm Pattern -- San Joaquin County Hydrology Manual

Low Loss Rate - When the rainfall intensity is less than the infiltration rate some runoff will still occur. Under these conditions the loss is taken as a fraction of the rainfall rate. Using both the low loss rate and the maximum loss rate in the determination of effective rainfall will result in 24-hr storm watershed yields that are approximately the same as given by the SCS Curve Number Approach (Hromadka *et al.* 1993).

Flood Routing and Detention Basin Analysis

Two types of flow routing are considered in the manual: streamflow routing and reservoir routing. The convex method for streamflow routing (Hromadka *et al.* 1993) is presented in the manual. Reservoir routing for detention basin design and analysis is based on the modified Puls' method. Because the 24-hr design storm may not be the "critical" storm for detention basin design, a multiday design storm is used for the analysis. Successive single-day storms are developed and added in front of the previously developed storm patterns until there is no additional volume required in the detention basin due to the extension of the duration of the design storm.

Conclusions

The hydrology manual prepared for the County of San Joaquin, California provides policy standards and guidelines for the county for the design of flood control and stormwater management projects. The manual is designed so that the results from application of its procedures will be consistent and fair, scientifically defensible and dependable, as well as reliable and reproducible when applied by different users. The procedures are relatively simple and easy to use, and are based on widely accepted hydrologic principles.

Measured discharges for determining flood flow frequency curves are available at only a few locations in the county. Runoff is computed from rainfall for specific frequencies and duration for design purposes. As a consequence of the uncertainty in computing an accurate value for the peak discharge associated with a specified frequency of a flood, the parameters in the manual were chosen to provide an 85% confidence level for the flood discharges. This helps to provide a "reasonable standard of care," since on a regional basis only 15% of the computed design discharges for a given recurrence frequency will be too small, and there is less liklihood of facilities being underdesigned.

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