UNIFORM DRAINAGE POLICIES AND STANDARDS EVALUATION

VOL. 2

EVALUATION OF HYDROLOGIC AND HYDRAULIC METHODS

NOVEMBER, 1986

Flood Control District
of
Maricopa County

Boyle Engineering Corporation
consulting engineers / architects

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FOR USE IN DRAINAGE ANALYSIS

MARICOPA COUNTY, ARIZONA

November 1986

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SUMMARY

This report presents an evaluation of hydrologic and hydraulic methods for use in drainage analysis within Maricopa County. Runoff modeling methods were evaluated including those for determining net runoff with empirical, unit hydrograph and hydraulic runoff models, along with hydrologic and hydraulic hydrograph routing techniques. Some hydraulic methods used in open channel and pipe design have also been described.

Following a general overview and classification of hydrologic and hydraulic methods, those used in Maricopa County, Albuquerque, Denver, El Paso, Las Vegas, Los Angeles and Pima County, as well as some other widely used methods, are described and examined. They are:

- Rational Method - an empirical method of estimating peak discharges, applicable for general use on drainage areas up to about 200 acres. Currently used or accepted for use by most all of the jurisdictions considered.

- Soil Conservation Service Methods (SCS TR-20/TR-55) - a dimensionless unit hydrograph using the curve number method to determine net runoff. Applicable for general use on drainage areas larger than about 1/10 square mile and used or accepted by many of the jurisdictions, including Albuquerque, El Paso and Las Vegas.

- ADOT Methods - simplified applications of SCS methods. Widely used in Maricopa County, but they may generally result in overestimation of discharge from small areas and underestimation from large areas.

- HEC-1 Flood Hydrograph Package - computer program that includes several methods for determining net runoff and for developing and routing hydrographs.

- SWMM Storm Water Management Model (Runoff Block) - hydraulic runoff and routing model, generally applicable for detailed analysis of urban drainage areas. Its routing capabilities are widely used in storm drain and drainage channel design.

- Colorado Urban Hydrograph Procedure (CUHP) - a calibrated Snyder synthetic unit hydrograph developed for the Denver area. Can be used interactively with HEC-1 and SWMM.

- Pima County Flood Control District's Method - the rational method with runoff coefficient (C) and time of concentration calibrated based on local and published data. Calibrated for use up to about 10 square miles.

- Los Angeles County Flood Control District's Methods - runoff model using a calibrated method based on a combination of the rational method and rainfall s-curves. Hydrograph routing by a kinematic wave method.

- Santa Barbara Urban Hydrograph - instantaneous unit hydrograph based on routing runoff through a single linear reservoir. Use limited to drainage areas less than about 3 square miles.

- Illinois Urban Drainage Area Simulator (ILLUDAS) and Penn State Runoff Models - Hydraulic runoff and routing models similar to SWMM.

- HEC-2 Water Surface Profile Program - a hydraulic computer program for estimation of water surface profiles for given flow rates in open channels and conduits.

- STORM Storm Drain Analysis Program - a steady state nonuniform flow program for hydraulic analysis of pipe systems.

Based on an evaluation of the merits and limitations of the above methods and an evaluation of the requirements of methods for general drainage analysis use in Maricopa County, the following recommendations are made:

For areas up to 160 acres:

- The rational method be used for computing peak discharges.

- Uniform methods of determining runoff coefficients and time of concentration that reflect conditions in Maricopa County be established.

- Uniform procedures for constructing triangular hydrographs be established. The hydrographs should be routed by direct translation if necessary.

For areas greater than 160 acres:

- Net runoff be determined by the SCS curve number method with uniform use of curve numbers established to provide for consistent results. The method should be calibrated for Maricopa County conditions.

- A unit hydrograph be used for synthesizing hydrographs and that the parameters defining this hydrograph be calibrated for Maricopa County conditions. The SCS dimensionless unit hydrograph may be used until a Maricopa County Unit Hydrograph is developed.

- The kinematic wave method be used for routing hydrographs.

- A hydrologic data collection program be implemented to aid in calibration of curve numbers and hydrograph parameters.

- A hydrologic computer program be developed for the Maricopa County Unit Hydrograph Procedure. This will assist in ensuring widespread use of the standardized methods and will facilitate changes made as the methods are calibrated.

1. INTRODUCTION

As part of the development of Uniform Drainage Standards and Policies for Maricopa County, hydrologic and hydraulic methods used in drainage analysis were evaluated for use in Maricopa County.

The hydrologic methods examined are those for estimating hydrographs and for routing hydrographs through open channels and reservoirs. Emphasis was placed on methods suitable for ungaged drainage areas with sizes from a few acres to about 10 square miles.

Hydraulic methods examined include those for hydrograph generation and routing and determination of water surface profiles in open channels and conduits for steady flow conditions. As the analysis of steady flow hydraulics is typically straightforward, only a few of the computer methods available for its analysis will be examined.

This paper first presents a general overview and classification of hydrologic and hydraulic methods, then lists and describes the methods used in Maricopa County, some of the methods used in other cities and counties of the southwestern United States, and other widely used methods. Finally, the methods are evaluated regarding their applicability for use in drainage analysis in Maricopa County and recommendations are made.

2. OVERVIEW OF HYDROLOGIC AND HYDRAULIC METHODS

Hydrologic and hydraulic methods are used in drainage analysis to model runoff based on precipitation data and the physical characteristics of the drainage areas. In general, hydrographs resulting from overland flows of small drainage areas are initially estimated. These hydrographs are then routed and combined as necessary through a conveyance system such as open channels, conduits and reservoirs.

2.1 RUNOFF MODELING

Using the data on physical basin characteristics and precipitation, the net runoff is determined and peak discharges or runoff hydrographs are derived using either empirical, unit hydrograph, or hydraulic methods. A general classification of runoff modeling methods is presented in Figure 1.

2.1.1 Determining Net Runoff

Net runoff is the quantity of runoff as calculated from the total precipitation minus the losses due to interception, depression storage and infiltration. These losses are generally accounted for by considering soil types, antecedent soil moisture, type and density of vegetation and the amount of impervious area.

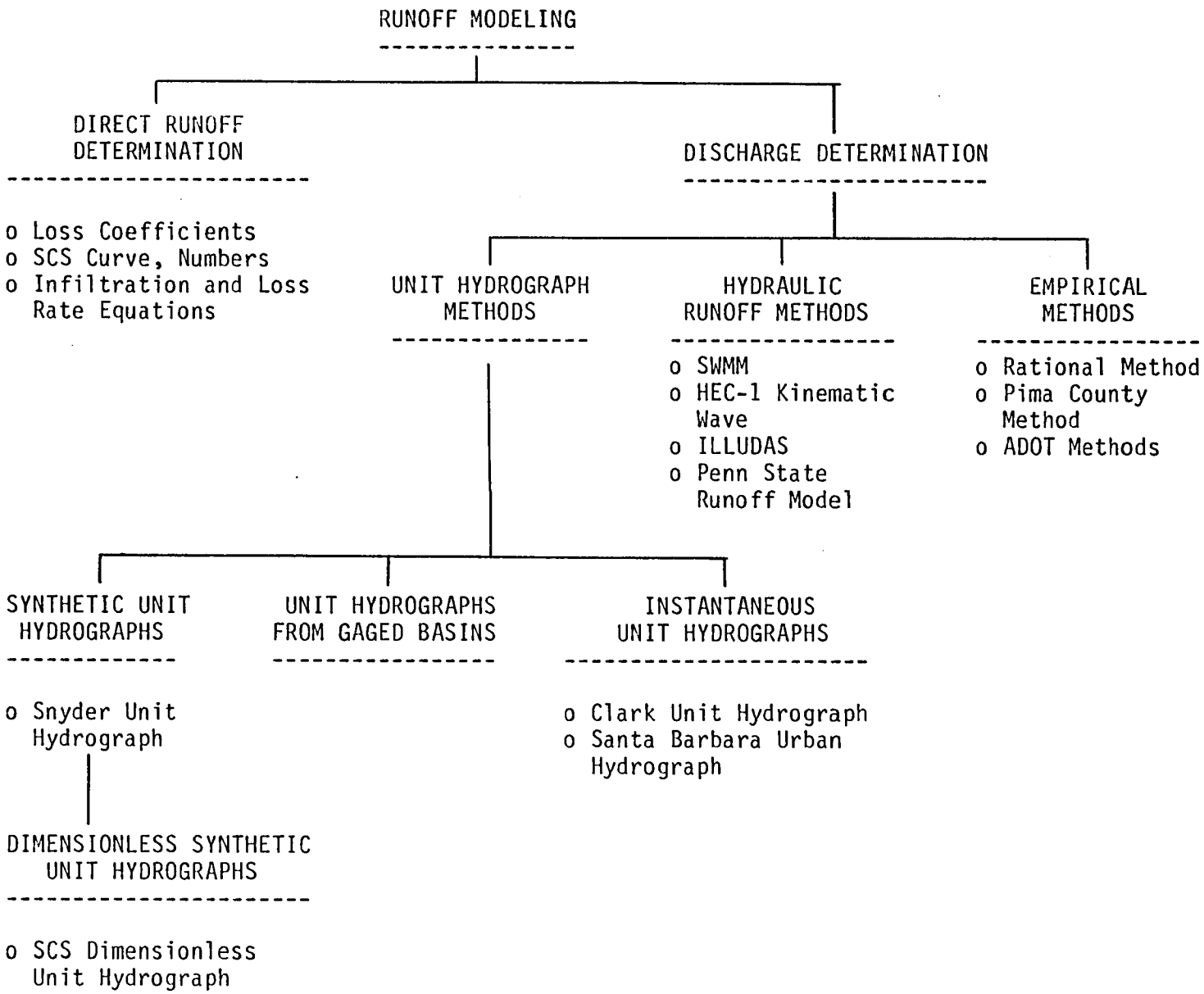


Figure 1 - Classification of Runoff Modeling Methods

Several methods are used to determine net runoff. The simplest method is to include losses within a coefficient as is done in empirical runoff methods. Runoff may also be determined using the curve number method, as developed by the Soil Conservation Service, or by using one of several infiltration and loss equations. These equations include the Horton, Holtan and Green-Ampt infiltration equations.

As rainfall losses can vary greatly, any local data that is available for verifying or calibrating the method used can significantly increase its accuracy in estimating net runoff.

2.1.2 Empirical Runoff Modeling Methods

Empirical methods were the first ones developed for predicting runoff. They relate peak discharges to easily measured drainage area characteristics. The most widely used empirical method is the rational method, which relates peak discharges to size of the drainage area, average rainfall intensity during the time of concentration, and a runoff coefficient C. Because the rational method greatly simplifies the rainfall-runoff process, its use is usually restricted to drainage areas less than about 200 acres (Chow, 1964).

2.1.3 Unit Hydrograph Methods

Unit hydrographs are hydrographs of one inch of direct runoff from precipitation of a specified duration. They were originally developed from the observed hydrographs of gaged drainage areas.

For ungaged drainage areas, the method of synthetic unit hydrographs was developed by Snyder (1938). Snyder's method uses generalized equations for lag time and unit hydrograph peak discharge along with coefficients derived from gaged basins similar to the one being modeled. The Colorado Urban Hydrograph Procedure developed for the Denver area is an example of a calibrated Snyder unit hydrograph.

A further development, based on the synthetic unit hydrograph, has been the dimensionless unit hydrograph, such as developed by the Soil Conservation Service. Parameters for a dimensionless synthetic unit hydrograph are based on average values obtained from many gaged basins. They are primarily for use where flow records are not available.

A further development from unit hydrograph theory has been the concept of the instantaneous unit hydrographs, resulting from effective precipitation of an infinitesimally small duration. Implicit in many instantaneous unit hydrograph methods is the assumption that the drainage area acts as a linear reservoir through which runoff is routed. Commonly used methods are the Clark Unit Hydrograph and the Santa Barbara Urban Hydrograph.

2.1.4 Hydraulic Runoff Modeling Methods

Runoff may also be modeled using hydraulic equations for overland flow. Drainage areas are divided into overland flow planes and excess precipitation is routed over these planes using kinematic wave routing, typically solving a continuity equation and Manning's equation iteratively. This approach is utilized in SWMM, ILLUDAS and the HEC-1.

Hydraulic runoff modeling can simulate the actual process in detail, but it still requires considerable judgement in the selection of correct Manning's n values for overland flow and appropriate subdivision of the drainage area into flow planes and connecting channels. The methods are impractical for hand calculations.

2.2 HYDROGRAPH ROUTING

Routing of a hydrograph through channels and reservoirs changes the peak discharge and the shape of the hydrograph. Hydrograph routing procedures may be classified as either hydrologic or hydraulic. Hydrologic routing methods use storage in a channel reach or reservoir along with the continuity equation. Hydraulic methods use the continuity equation in conjunction with the energy equation or Manning's equation for routing hydrographs. Hydrographs may also be routed by direct translation, where the hydrograph is routed downstream at an average velocity with its shape unchanged. Direct translation is simple but it is also conservative as peak discharges are not attenuated. Figure 2 presents a classification of hydrograph routing methods.

2.2.1 Hydrologic Routing Methods

Hydrologic methods for routing hydrographs use the continuity equation along with channel or reservoir storage information. Hydrologic routing methods can be divided into storage methods and lag methods.

Storage routing methods include level-pool routing, the modified Puls method, the Muskingum method, and the working-value method. Level-pool routing (also called the Puls method) and the modified Puls method assume an invariable discharge-storage relationship, assuming that for each storage in a channel reach or reservoir there is a unique discharge. This assumption is appropriate for reservoir routing, but as stated by the Corps of Engineers (1981) with regards to the modified Puls method, "caution must be used when applying this method to channel routing, since the results depend on selecting reservoir-type routing parameters which accurately mimic the physically different process of channel routing".

A variable discharge-storage relationship, one that accounts for wedge storage, is frequently required when storage methods are used for open channel routing. The Muskingum method and the working-value method (also called the working R and D method) both account for wedge storage. Routing coefficients are required for both methods. These are usually derived from flood records, but may be obtained from physical channel characteristics (channel geometry, estimated roughness coefficients).

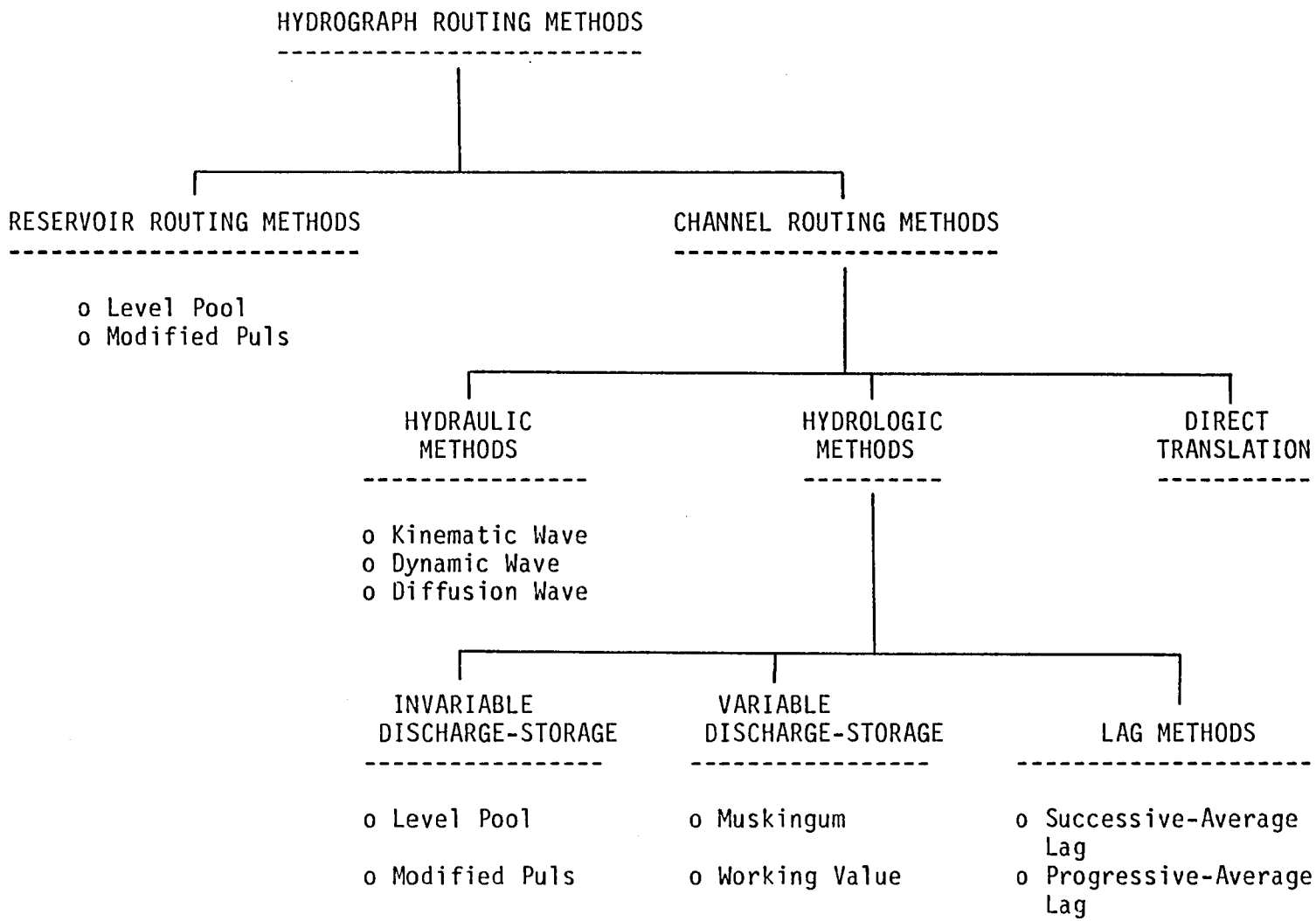


Figure 2 - Classification of Hydrograph Routing Methods

Lag methods are empirical routing methods based on the time displacement of average inflows. Methods available include the successive average-lag method (Tatum method) and the progressive average-lag method (Straddle-Stagger Method). Lag methods have been applied primarily to long reaches of slowly fluctuating streams and because of their empirical nature, their reliability and applicability is limited (Chow, 1964).

In summary, the level-pool and modified Puls methods work well for reservoir routing of hydrographs. For channel routing using hydrologic routing methods, variable storage-discharge methods (Muskingum, working value) are widely used, requiring either flood data or channel geometry and roughness coefficients. Lag methods and invariable discharge-storage relations may be used if results can be verified by comparison with gaged flows.

2.2.2 Hydraulic Routing Methods

Hydraulic methods for routing hydrographs are based upon solutions to the energy equation along with the continuity equation. Depending upon the method chosen, some or all of the terms of the energy equation may be utilized (see Henderson, 1966, for a theoretical discussion of using the complete energy equation in flood routing). The primary hydraulic routing methods are the kinematic wave, dynamic wave and diffusion wave methods.

Kinematic wave routing is based on a uniform flow assuming that the friction slope is equal to the bed slope. This simplifies computations and allows Manning's equation to be used for computation of discharge in the continuity equation. The kinematic wave method is often appropriate for typical channels in urban areas (Corps of Engineers, 1981) or for natural channels with slopes greater than 10 feet per mile (Henderson, 1966).

For channels requiring use of the complete energy equation, dynamic wave routing is needed. The mathematics associated with it, however, are fairly complex, and are often solved using numerical methods. Therefore, unless modeling a major river system, routing by the dynamic wave method is not used and flows are approximated using either storage methods or kinematic wave methods. Similarly, the diffusion wave method, which introduces a diffusion term into the modeling of a floodwave, is seldom used in drainage work because of its mathematics and also because of the only approximately known nature of the diffusion term.

2.3 STEADY FLOW HYDRAULICS

Once a design discharge rate is determined using the procedure described in the above sections, a hydraulic analysis is required to estimate water surface profiles or to develop hydraulic design criteria for the runoff conveyance system under consideration. When a conveyance system has a uniform shape and does not influence downstream hydraulic conditions (backwater), the normal depth using Manning's equation is commonly used to estimate water surface elevations or velocities. However, if a conveyance system has an irregular shape, or a substantial backwater effect exists, the hydraulic analysis is performed utilizing the energy equation. Two commonly used computer programs for this purpose are: HEC-2 for open channel flow analysis and STORM for pipe flow analysis.

3. DESCRIPTION AND USE OF HYDROLOGIC AND HYDRAULIC METHODS

For drainage analysis, many of the hydrologic and hydraulic methods discussed in Section 2 are either used or accepted for use by the jurisdictional agencies of Maricopa County. These methods are either used individually or may be incorporated as part of larger computer programs. In addition, other western jurisdictions use many of the same methods or have developed their own methods. The policies of the jurisdictional agencies of Maricopa County and of the other western areas with regards to the use of hydrologic and hydraulic methods are listed below. Following the listing, the individual methods and the computer programs (along with some widely used ones not listed below) are described with regards to their capabilities and data requirements, their classification and range of applicability.

3.1 POLICIES REGARDING USE OF HYDROLOGIC AND HYDRAULIC METHODS

The jurisdictions within Maricopa County have policies regarding the use of methods for runoff modeling, hydrograph routing, and steady flow hydraulics in drainage analysis. These policies are listed below. Other western jurisdictions - including Albuquerque, Denver, El Paso, Las Vegas, Los Angeles and Pima - have similar policies, which are also presented.

3.1.1 Maricopa County Policies

Runoff Modeling Methods. The runoff modeling methods commonly used within Maricopa County include:

- Rational Method
- Soil Conservation Service Methods (TR-20/TR-55)
- Arizona Department of Transportation Methods
- U.S. Corps of Engineers HEC-1 model
- Storm Water Management Model (SWMM)

Policies of the Maricopa County jurisdictions (as of September, 1985) regarding use of these runoff models are:

Phoenix - The rational method maybe used for up to 1/10 square mile drainage areas. For over 1/10 square mile drainage areas, ADOT methods or SCS TR-20/TR-55 are required.

Scottsdale - The rational method may be used for up to 1 square mile drainage areas. For drainage areas over 1/10 square mile ADOT methods are accepted. SCS TR-20/TR-55, HEC-1 and other approved methods are also accepted.

Glendale - The rational method is primarily used. SCS TR-20/TR-55 and other method used with approval. SWMM is used in storm drain studies.

Tempe - The rational method is used for most areas. SCS TR-20/TR-55 is also accepted.

Mesa - The rational method is used for all drainage areas.

FCDMC	- SCS TR-20/TR-55, ADOT methods, HEC-1, the rational method and other technically sound methods are accepted.
Gilbert	- The rational method is used for drainage areas of up to 100 acres. SCS TR-20/TR-55 is also accepted.
Peoria	- The rational method, ADOT methods and SCS TR-20/TR-55 are all accepted. SWMM is used in developed drainage areas.
Goodyear/ Wickenburg	- Any technically sound method may be accepted.
Youngtown	- The rational method and ADOT methods are accepted.
Apache Junction	- The rational method is used for most drainage areas.

Other cities and towns within Maricopa County may lack firm policies, but generally accept the same methods. Most of the jurisdictions also have some standard values for the coefficients used in the different methods, (i.e., curve numbers, runoff coefficients in the rational method, etc.). Approval is often required for use of other coefficients or other methods.

Hydrograph Routing Methods. Policies for hydrograph routing by Maricopa County jurisdictions are limited. Most have adopted the methods used in the ADOT manuals which show direct translation of the hydrographs. (As mentioned previously, direct translation is conservative as peak discharges are not attenuated, but the method is relatively simple to understand and use.)

Use of TR-20, SWMM or HEC-1 allows the use of routing methods included in these programs, which are generally accepted. With HEC-1, which contains six routing options, no written policies were found regarding which are accepted and it is assumed that approval would be needed for use of some of them.

Hydraulic Methods. As most hydraulic methods used for open channel and pipe design are consistent (compared to runoff modeling methods), the policies of the Maricopa County jurisdiction regarding their use are all very similar. They all allow or require the use of Manning's equation for energy loss estimation, for example. Differences occur in the level of detailed analysis required (such as under when backwater calculations are required) rather than in the methods used. Hydraulic programs such as HEC-2 and STORM are accepted.

3.1.2 Policies of Jurisdictions Outside of Maricopa County

The policies of Albuquerque, Denver, El Paso, Las Vegas, Los Angeles and Pima County regarding runoff modeling and hydrograph routing methods are presented below. As discussed in the preceding paragraph, hydraulic methods are straight forward and policies of these jurisdictions with regard to hydraulic methods vary little.

Runoff Modeling Methods:

Albuquerque Metropolitan Arroyo Flood Control Authority
The rational method for drainage areas up to 320 acres. For larger drainage areas, any method which is in accord with the generally accepted methods of hydrology.

Denver Urban Drainage and Flood Control District
The rational method is used for drainage areas up to 160 acres. The Colorado Urban Hydrograph Procedure (a locally calibrated synthetic unit hydrograph) is used for drainage areas greater than 90 acres. SWMM is also used if calibrated against CUHP results.

City of El Paso
The rational method is accepted for use on all sizes of drainage areas.

Clark County, Nevada
The rational method is accepted for use on small drainage areas. SCS TR-20/TR-55 used for all drainage areas.

Los Angeles County Flood Control District
Capital Flood Hydrology Method used for all drainage areas. Based on a calibrated, modified rational method using cumulative runoff from a 4-day storm.

Pima County Flood Control District
A calibrated rational method used for all drainage areas. It is calibrated with local and published data.

Hydrograph Routing Methods:

Albuquerque Metropolitan Arroyo Flood Control Authority, City of El Paso and Clark County, Nevada
Policies similar to Maricopa County jurisdictions.

Denver Urban Drainage and Flood Control District
Hydrographs can be routed by any appropriate, sound routing techniques including direct translation, Muskingum, convex and storage routing methods.

Los Angeles County Flood Control District
Hydrographs routed based on travel time and estimated channel storage. The method appears to be a simplified kinematic wave procedure.

Pima County Flood Control District
The routing of subarea flows is only approximated (weighted averages of subarea characteristics are used to compute the total basin outflows.) No channel routing method is specified.

3.2 DESCRIPTION OF HYDROLOGIC AND HYDRAULIC METHODS

The hydrologic and hydraulic methods listed above and several additional methods are described with regard to their capabilities and data requirements and are examined with regard to their classification and range of applicability. Each method is presented in the following format:

Description	General description of the method and its use.
Determining Net Runoff	Description of the methods used to determine net runoff
Peak Discharges and Hydrographs	Description of the methods used for estimating peak discharges and developing hydrographs.
Routing Hydrographs	Description of methods used for routing hydrographs.
Range of Applicability	Limits, such as drainage area size, that restrict the use of the method.
Use of Method	How the method is used and whether it is suitable for hand calculations or if computers are required.
Comments	Comments regarding who uses the method and how, and general comments regarding the use of the method for drainage analysis in Maricopa County.

The methods described and examined are:

Methods currently used in Maricopa County

- Rational Method
- SCS TR-20/TR-55
- ADOT Methods
- HEC-1
- SWMM

Methods used in other western jurisdictions

- Denver Urban Drainage and Flood Control District - Colorado Urban Hydrograph Procedure (CUHP)
- Pima County Flood Control District's Methods
- Los Angeles County Flood Control District's Methods

Additional widely used methods

- Santa Barbara Urban Hydrograph
- Illinois Urban Drainage Area Simulator (ILLUDAS)
- Penn State Runoff Model
- HEC-2
- STORM

3.2.1 Rational Method

Description - Empirical method for estimating peak discharges, applicable for general use on small drainage areas.

Determining Net Runoff - Rainfall losses included in a runoff coefficient C which ranges from zero to one. C may be estimated based on soil type, vegetation, percent imperviousness and intensity of rainfall.

Peak Discharges and Hydrographs - Peak discharges based on the equation

$Q = CiA$ - where: Q = peak discharge
i = rainfall intensity
C = coefficient

The rainfall intensity is assumed to be from a storm of a duration equal to the time of concentration.

Routing Hydrographs - Hydrograph routing is not part of the method. When needed, the triangular hydrographs are usually routed by direct translation.

Range of Applicability - Assumptions involved in the method are most applicable to small urban drainage areas. Use should be limited to areas less than about 200 acres (Chow, 1964).

Use of Method - Suitable for hand calculations. Standard methods for determining C and the time of concentration should be established. The method can be calibrated for local conditions (see 3.2.7, Pima County Method).

Comments - The rational method is used by most all the jurisdictions considered. Its use does not require specialized hydrologic knowledge and it may be calibrated. Unless calibrated, however, its use should be restricted to small drainage areas.

3.2.2 Soil Conservation Service Methods (TR-20/TR-55)

Description - A dimensionless unit hydrograph developed by the Soil Conservation Service and the SCS curve number method for determining net runoff.

TR-20 is Technical Release 20, Computer Program for Project Formulation - Hydrology, a computer program that uses the SCS methods. TR-55 is Technical Release 55, Urban Hydrology for Small Watersheds, a guide to the use of SCS methods for urbanizing watersheds. It contains graphical and tabular solutions for peak discharges and hydrographs. A revised edition of TR-55 is expected in 1986.

Determining Net Runoff - Net runoff is determined by the SCS curve number method. It is computed as:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

where: Q = total runoff;
P = total precipitation;
S = potential abstraction (infiltration + initial abstraction);
$= \frac{1000}{CN} - 10$
CN = curve number

Curve numbers are based on soil types, vegetation, impervious cover and antecedent moisture conditions.

Peak Discharge and Hydrographs - Peak discharges and hydrographs are derived using a dimensionless unit hydrograph developed by SCS. The equation for each unit hydrograph peak discharge is:

$$q_p = \frac{484\ A\ Q}{t_p}$$

where: 484 = 640 x C_p, 640 is a unit conversion factor;
C_p = Snyder's hydrograph peak coefficient
t_p = time to peak;
= D/2 + L = D/2 + 0.6 t_c;
D = duration of unit excess rainfall;
L = basin lag, time from center of mass of excess rainfall to time of peak, approximately = 0.6 t_c;
t_c = time of concentration (D = 0.1 t_c to 0.2 t_c);
Q = runoff amount for the duration D.

The equation is based on the Snyder unit hydrograph equation with average peak factor of 0.75. (484 is an average of values of from 300 (wetlands) to 600 (steep mountains). Basin lag calculated by SCS lag method or by the upland method. Total hydrograph peak discharges are found by summing unit hydrographs throughout the duration of a storm.

Routing Hydrographs - Hydrograph routing is an option of TR-20, with hydrographs routed through channels by the Modified Att-Kin method, a combination of storage routing (attenuation) and kinematic wave routing.

Range of Applicability - Applicable for drainage areas of up to about 50 square miles. Limited to a minimum size of about one-tenth of a square mile (the lower limit of most unit hydrographs). As the method is essentially a nationwide average of unit hydrograph parameters, its reliability may be significantly increased by calibrating to local conditions.

Use of Method - The SCS unit hydrograph methods may be performed by hand calculations, although time consuming. The tables and graph of TR-55 were developed to eliminate much of the need for hand calculations. The program TR-20 may be used on either a micro or mainframe computer.

Comments - SCS TR-20/TR-55 is widely used in Maricopa County and elsewhere. Its use is relatively straight forward and well documented, and it can be easily calibrated if data is available.

3.2.3 Arizona Department of Transportation Methods

Description - The ADOT methods are a simplified application of the SCS methods. The SCS curve number method is adapted for one through six hour storms and the unit hydrograph peak discharge equation is adapted for total hydrograph peak discharges.

For drainage areas less than 10 square miles the method used is referred to as Part I. Part II is for greater than 10 square miles.

Determining Net Runoff - The SCS curve number method, as discussed in section 3.2.2, is used for 1, 2, 3 and 6-hour storms. Precipitation is assumed uniform for the storm, rather than varying as with the SCS design storm procedure.

Also, with ADOT's use of the method, precipitation losses occur uniformly over the period of precipitation (i.e., during the 1 through 6 hours). Using the SCS method, the precipitation loss rate varies with time and depends on intensity of precipitation.

Peak Discharges and Hydrographs - ADOT uses the SCS unit hydrograph peak discharge equation for determining total hydrograph peak discharges. Hydrographs are assumed to be triangular.

ADOT Part I - For drainage areas less than 10 square miles, total hydrographs are determined by the SCS equation ($Q_p = 484\ AQ/t_p$) with Q being the 1-hour storm runoff and t_p equal to the time of concentration times a width factor.

ADOT Part II - For drainage areas greater than 10 square miles, ADOT calculates peak discharges, using the same equation, for 1, 2, 3 and 6 hour storms, and the largest peak discharge is selected. For this method, however, t_p is defined as being equal to $D/2 = 0.6\ t_c$, where D = 1, 2, 3 or 6 hours.

Overall, a unit hydrograph peak discharge equation should not be used to estimate total hydrograph peak discharges (Figure 3 illustrates the differences). Therefore, the ADOT methods are a misapplication of the SCS methods for estimating peak discharges.

Routing Hydrographs - The triangular hydrographs developed using the ADOT methods are routed by direct translation.

Range of Applicability - ADOT methods are generally used for drainage areas of about 1/10 square mile and up. For small areas, however, peak discharges are generally overestimated and for large areas they may be underestimated.

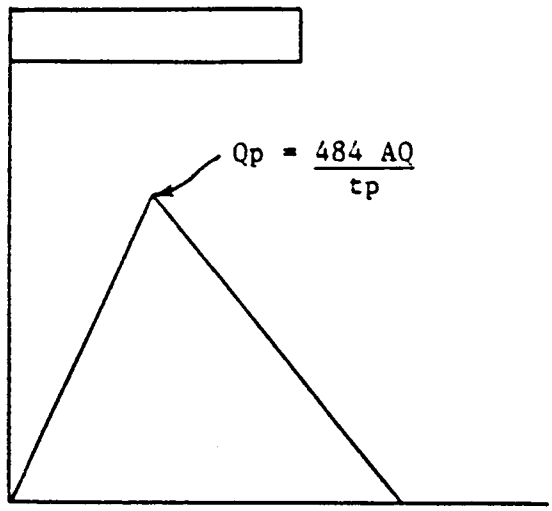
Use of Method - The ADOT methods are widely used in Maricopa County. They are suitable for hand calculations.

Comments - The ADOT methods are not the same as the SCS TR-20/TR-55 methods. Their use is discouraged as peak discharges may be either overestimated for small drainage areas or underestimated for large areas. (Note: ADOT has recently (1987) changed its policies to require use of SCS methods.)

ADOT SCS Part I Method

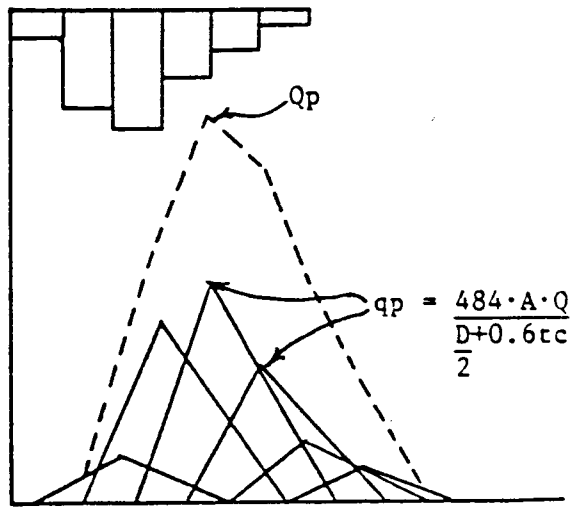
SCS TR-20/TR-55 Method -
Using Triangular Unit Hydrographs

Precipitation - Uniform



Time

Precipitation - Variable



Time

Figure 3 - Comparison of ADOT SCS and SCS TR-20/TR-55 Methods

3.2.4 HEC-1 Flood Hydrograph Package

Description	-	HEC-1 is a computer program developed by the U.S. Army Corps of Engineers that includes several methods for determining net runoff and developing hydrographs, and for routing hydrographs. It is also capable of optimizing hydrograph parameters and performing economic and dam safety analyses.
Determining Net Runoff	-	For determining net runoff, HEC-1 has four runoff loss methods (initial loss and uniform loss rate, exponential loss rate, SCS curve numbers, and Holtan loss rate), along with routines for snowmelt and channel infiltration, and four options for precipitation input (precipitation hydrographs, historical storms, standard project storms, or synthetic storms from depth-duration data).
Peak Discharges and Hydrographs	-	HEC-1 has three unit hydrograph methods and one hydraulic runoff modeling method. The unit hydrographs are the Clark method, the Snyder unit hydrograph, and the SCS dimensionless unit hydrograph. The parameters for the Clark and Snyder methods may be optimized by HEC-1. The hydraulic runoff method is a kinematic wave method for overland and channel flow. It is based on the Massachusetts Institute of Technology Catchment Model (MITCAT).
Routing Hydrographs	-	HEC-1 has seven hydrograph routing options. Along with routing hydrographs, channel losses, flow diversions and pumping plants may be modeled. For reservoir routing, level pool and modified Puls routing are available. Reservoir routing may be modeled in much detail if necessary. For channel routing, Muskingum, modified Puls, working R and D, kinematic wave and two lag methods are all available.
Range of Applicability	-	HEC-1 is one of the most comprehensive models available. It may be used for drainage areas ranging in size from hundreds of square miles down to the lower limits of the runoff methods (such as a few acres for the kinematic wave method).
Use of Method	-	HEC-1 may be used on either micro or mainframe computers. It is used in Maricopa County with its SCS method options.
Comments	-	As stated above, HEC-1 is one of the most comprehensive models available. It can be used in the same capacity as TR-20, but with more options (TR-20 in itself an option in HEC-1).

3.2.5 Storm Water Management Model (SWMM)

Description - SWMM is a runoff and water quality model developed by the Environmental Protection Agency. The runoff block of SWMM models runoff and routes hydrographs hydraulically.

SWMM has been updated several times. Major changes, however, have generally been restricted to the water quality routines. Currently the most widely used versions (for runoff modeling) are Version III with Addendum I - Extran and the Corps of Engineers - Missouri River Division version.

Determining Net Runoff - Net runoff from a design storm is determined by accounting for depression storage on both pervious and impervious surfaces and using infiltration equations for losses on pervious areas. The infiltration equations used are Horton and Green-Ampt. Horton's equation is available only in the Corps of Engineers version.

Peak Discharges and Hydrographs - SWMM develops complete hydrographs by hydraulically routing runoff over land and through channels. The method used is a simplified kinematic wave procedure using Manning's equation for overland flow.

Routing Hydrographs - Hydrographs are routed through channels (gutters, open channels, pipes) by the kinematic wave method based on Manning's equation. Flows may be diverted if channel capacities are exceeded in the Missouri River Division version.

Addendum I to Version III is a dynamic hydrograph routing block called Extran. It considers the full components of the energy equation for unsteady flow.

Range of Applicability - SWMM may be used for drainage areas from a few acres in size on up. It is limited on larger areas by the detail it requires, as this increases its data and time needs.

Use of Method - SWMM is often used in urban areas for storm drain sizing, as it conveniently models pipe networks. It has been used in Glendale, Peoria and Scottsdale in Maricopa County. It is also used in Denver, with its runoff results calibrated against CUHP results. SWMM is available for both micro and mainframe computers.

Comments - SWMM is probably best suited for modeling small urban drainage areas with storm drain systems. Both Version III and the Missouri River Division Version have advantages, although Version III is most widely used.

3.2.6 Colorado Urban Hydrograph Procedure (CUHP)

Description - CUHP is a calibrated Snyder synthetic unit hydrograph developed for the Denver area.

Determining Net Runoff - Runoff is calculated using Horton's infiltration equation. Detention storage and amount of impervious cover are also considered. Parameters used in Horton's equation have been calibrated for the Denver area.

Peak Discharges and Hydrographs - The Snyder unit hydrograph has been calibrated for the Denver area based on calibration studies for 17 drainage areas.

Both the unit hydrograph peak discharge equation ($q_p = 640 C_p A Q/t_p$) and the lag equation, as developed by Snyder, have been modified. The peak coefficient and time coefficient are both presented as functions of imperviousness.

Routing - The CUHP computer program does not include a hydrograph routing procedure. It is recommended that the routing be accomplished using HEC-1, SWMM or other appropriate methods.

Range of Applicability - CUHP is used for drainage areas ranging in size from 90 acres to 10 square miles (the rational method is used below 90 acres and up to 160 acres).

Use of Method - The CUHP may be used with hand calculations but is typically used with micro or mainframe computers. The program developed for its use is also interactive with SWMM and HEC-1 for hydrograph routing purposes.

Comments - Calibrated synthetic unit hydrographs are also used in San Bernardino County, California; Austin, Texas; and Tulsa, Oklahoma.

3.2.7 Pima County Flood Control District's Method

Description - The Pima County Flood Control District has calibrated the runoff coefficient and time of concentration of the rational method. The calibrated method is used for up to 10 square mile drainage areas.

Determining Net Runoff - The runoff coefficient, C, is calculated using an "adjusted curve number" procedure. Basically, SCS curve numbers are determined for the drainage area, the curve numbers are adjusted (based on the calibration study) and the adjusted curve numbers are used to find a runoff-rainfall ratio (C).

Peak Discharges and Hydrographs - Only peak discharges are calculated. The formula used is:

$Qp = 1.008\ q\ A$

or

$Qp = 1.008\ C_w\ i\ A$

where: A = area (acres);
1.008 = unit conversion factor;
q = runoff supply rate
= (C_w x i)
C_w = weighted runoff ratio
i = rainfall intensity

This is the rational formula, Q = C i A, with the unit conversion factor included (which is typically disregarded as insignificant).

Time of concentration is found from a calibrated and modified version of Snyder's lag equation. The equation includes a basin factor and also the rainfall intensity. As the time of concentration is expressed as a function of rainfall intensity, solution of the equation is iterative.

Routing Hydrographs - No hydrograph routing method is specified. The manual states that if a large drainage area is nonhomogenous, weighted parameters should be calculated and the basin treated as a whole. More standard hydrologic practice would be to divide the area into subdrainages and route their hydrographs.

Range of Applicability - The method is used for drainage areas up to 10 square miles and was calibrated for this range. This is much beyond the usual limits of the rational method, based on its inherent assumptions, and the calibration data and methods would need to be assessed before concluding the method is indeed valid for use on the larger drainage areas.

Use of Method - Suitable for hand calculations.

Comments - While use of a rational method on large drainage areas is questionable from a theoretical viewpoint, certain portions of it may be applicable to Maricopa County. In particular the C values may be appropriate for use where the rational method is used and the time of concentration equation may be applicable to large basins in Maricopa County. (The equation is of the type often used with unit hydrographs.) Overall, the collected data used in the method's calibration may be most useful.

3.2.8 Los Angeles Flood Control District's Methods

Description - The Los Angeles County Department of Public Works method models runoff using a calibrated method based on a combination of the rational method and rainfall s-curves.

Determining Net Runoff - Local infiltration data is applied to a four day rainfall mass curve.

Peak Discharges and Hydrographs - Discharges are determined by use of the rational method at discrete time intervals during the duration of the design storm. Hydrographs are the result of summing the separate discharge calculations.

Routing Hydrographs - Hydrographs are routed by a simplified kinematic wave method.

Range of Applicability - Used on most sizes of drainage areas, with larger drainage divided into small areas.

Use of Method - Suitable for hand calculations but more commonly used with a computer program (available from LA County).

3.2.9 Santa Barbara Urban Hydrograph

Description - The Santa Barbara Urban Hydrograph is an instantaneous unit hydrograph based on routing runoff through a single linear reservoir.

Determining Net Runoff - In the original model, runoff was determined using a constant loss rate equation. Other equations, such as Green-Ampt, have also been used with it.

Peak Discharges and Hydrographs - Hydrographs are determined by using an instantaneous unit hydrograph combined with the concept of a single linear reservoir. Runoff is routed through the reservoir to account for storage in the drainage area. A routing coefficient is needed and is assumed equal to the time of concentration.

Routing Hydrographs - No hydrograph routing method is specified for the method.

Range of Applicability - Applicable to small urban drainage areas up to about 2 to 3 square miles in size. Due primarily to the assumptions regarding the storage coefficient, use on larger drainage areas may result in it overestimating peak discharges.

Use of Method - May be used with HP41 series programmable calculators or computers.

Comments - Has been used on a small tributary of the Agua Fria River, Maricopa County, with good success (Pederson, 1980).

3.2.10 Illinois Urban Drainage Area Simulator (ILLUDAS)

Description - ILLUDAS is a hydraulic runoff and routing model developed by the Illinois State Water Survey.

Determining Net Runoff - Runoff determined using Horton's infiltration equation and depression storage estimates.

Peak Discharges and Hydrographs - Runoff is determined from connected and unconnected paved areas, and pervious areas with the total from the areas contributing to the hydrographs. Hydrographs are determined based on travel times using Izzard's equations for overland flow.

Routing Hydrographs - Hydrographs may be routed using either kinematic wave or storage methods. They can be routed through open channels, detention basins and pipe systems.

Range of Applicability	-	Limited by the amount of detailed data that can be gathered, usually used for less than 5 square mile drainage areas. As pervious area runoff is not modeled in much detail, the method is most applicable to urbanized areas.
Use of Method	-	Not for hand calculations; micro or mainframe computers are needed. The method has been used in many urban areas in essentially the same manner as SWMM is used.
Comments	-	Best used for detailed studies of small urban areas.

3.2.11 Penn State Runoff Model

Description	-	The Penn State Runoff Model is a hydraulic runoff and routing model similar to SWMM and ILLUDAS.
Determining Net Runoff	-	Runoff is determined using the SCS curve number method.
Peak Discharges and Hydrographs	-	Hydrographs are determined using Manning's equation for overland flow.
Routing Hydrographs	-	Hydrographs may be routed through detention basins, pipes and channels. Direct translation is used for routing through channels and pipes.
Use of Method	-	Requires a computer for use. Being a hydraulic runoff model, its use is limited by the size of basin that can be modeled in detail.
Comments	-	The Penn State Runoff Model was originally developed to analyze needs for detention basins and other facilities in drainage areas that contribute to critical flooding problems. Its use is similar to SWMM and ILLUDAS although its routing procedures are simpler.

3.2.12 HEC-2 Water Surface Profiles Program

Description	-	HEC-2 is a steady state nonuniform flow program for analysis of flows in open channels.
Flow Analysis	-	Flow analysis is one-dimensional with a non-movable bed using Manning's equation and the standard step backwater procedure. Program options include flow through bridges, channel improvements, and split flow analysis.
Range of Application	-	Use of HEC-2 is limited to channels where flow is gradually varied (a hydrostatic pressure distribution exists), the flow is essentially one-dimensional and slopes are small (less than about ten percent, so depth of flow may be measured by its vertical component).
Use of Method	-	HEC-2 may be used on both micro and mainframe computers. It is widely used and accepted.

3.2.13 STORM Storm Drain Analysis Program

Description	-	STORM is a steady state nonuniform flow program for analysis of flows in pipe systems.
Flow Analysis	-	Flow analysis is one-dimensional using Manning's equation and the standard step backwater procedure. Flow may be either full pipe (pressure or non-pressure flow) or with a free surface. Pressure-momentum is used for hydraulic jump calculations and may also be used for junction losses.
Range of Applicability	-	Use of STORM is limited to essentially the same flow conditions as is HEC-2, that is pipes where flow is gradually varied (a hydrostatic pressure distribution exists), the flow is essentially one-dimensional and slopes are small (less than about ten percent, so depth of flow may be measured by its vertical component).
Use of Method	-	STORM is a microcomputer program developed from the Los Angeles Flood Control District's mainframe storm drain analysis program. It is widely used and accepted.

4. EVALUATION OF HYDROLOGIC AND HYDRAULIC METHODS FOR USE IN MARICOPA COUNTY

Based on evaluation of the hydrologic and hydraulic methods described and examined in the preceding sections and the requirements for drainage analysis, runoff modeling and hydrograph routing methods suitable for general use in Maricopa County are recommended in this section. Suggestions for calibrating these methods and facilitating their use are also made.

4.1 REQUIREMENTS FOR DRAINAGE ANALYSIS

The design of drainage facilities such as open channels, culverts, storm drains, retention and detention basins requires drainage analysis to estimate peak discharges and hydrographs. The runoff modeling and hydrograph routing methods must be reasonably reliable and provide consistent results when used by different designers.

The drainage analysis requires different levels of effort from the standpoints of economical consideration and accuracy desired. For example, the design of a small culvert draining only a few acres may only justify a simple estimate of peak runoff, while a major storm drain serving a large area may require more detailed hydrologic study. Deciding when simple methods are appropriate and when more sophisticated methods are needed depends not only on the size of the drainage area but also the types of the drainage facilities planned, and the levels of confidence associated with the various hydrologic methods available. For consistent use of methods, small and large sizes of drainage areas need to be defined.

A well designed drainage system needs to be balanced. That is, its components are neither undersized nor oversized with respect to each other. As many different designers may be involved in the design of facilities within a single drainage area, methods used for drainage analysis must be consistent. Standard procedures need to be established.

Finally, drainage analysis requires reasonably reliable results. Runoff modeling methods, in particular, are difficult to assess in terms of reliability. In the absence of local data for calibrating methods (which is by far preferred), the assessment of reliability must be based on the theoretical limits of a method and on the users' judgment as to whether the results obtained using average coefficients and parameters (i.e., values published in user's manuals) are reasonable.

In summary, consistent drainage analysis requires runoff modeling and hydrograph routing methods to be specified for use on small and large drainage areas. Uniform parameters should also be defined for each method. Ideally, these parameters should be developed based on measured local data. In the absence of such data, reasonable parameters may be developed using the experiences of other areas with similar conditions. A local program can then be established to collect data and monitor the effectiveness of the parameters in order to calibrate them.

4.2 EVALUATION OF RUNOFF MODELING METHODS

4.2.1 Runoff Modeling on Small Drainage Acres

As discussed in the previous section, relatively simple runoff modeling methods are usually sufficient for designing drainage facilities for smaller drainage areas. Currently the rational method is accepted by most all of the Maricopa County jurisdictions and by most of the other jurisdictions reviewed in this study. Other methods that may be used for small drainage areas include hydraulic runoff methods such as SWMM and ILLUDAS and simple unit hydrograph methods such as the Santa Barbara Urban Hydrograph. Other unit hydrographs, such as SCS and Snyder's may be used, but as they were originally developed for large basins, their use is generally limited to areas greater than about one-tenth square mile. For example, Denver has found that the CUHP overestimates runoff from small areas and discourages its use below 90 acres.

The rational method is based on simple assumptions regarding the rainfall-runoff process which generally are not valid when applied to areas greater than about 200 acres, although the method has been applied to larger areas. (This has been done, for example, by the Pima County Flood Control District, which calibrated the time of concentration and C values in order to extend its use.) Only peak discharges are calculated by the rational method. If hydrographs are needed they are typically assumed to be triangular. While the rational method does not model runoff in the detail of other methods, neither does it require specialized hydrologic knowledge.

SWMM, ILLUDAS and the Santa Barbara Urban Hydrograph all model the runoff process in more detail than the rational method, and all calculate complete hydrographs rather than only peak discharges. They also require the user to have more knowledge of hydrology than is required for use of the rational method. Hydraulic runoff methods (SWMM, ILLUDAS) are not practical for hand calculation. For the Santa Barbara Urban Hydrograph, hand calculations are time consuming.

Overall, it can be argued whether the extra detail in modeling provided by SWMM, ILLUDAS, the Santa Barbara Urban Hydrograph, and similar methods results in significantly greater accuracy than produced by use of the rational method. On small drainage areas, approximately the same runoff estimates are obtainable from proper use of the rational method as with more sophisticated methods. Proper use of the rational method requires appropriate C values and times of concentration, which may be obtained by calibration with field data, from already calibrated models such as the Pima County method, or possibly even from calibration against a model such as SWMM.

Based on the advantages and disadvantages of the various methods discussed above, it is recommended that the rational method be used for small drainage areas and that uniform methods be established for determining the runoff coefficients, time of concentration, and hydrograph shape. It is further recommended that the runoff coefficients be related to factors such as soil type, vegetation, percent imperviousness and the return period of the storm, and that they be calibrated as local data reflecting conditions in Maricopa County becomes available. Since the use of the rational method is limited to areas of about 200 acres or less, and since drainage areas in urban areas are often delineated by land parcels, typically 160 acres (one-quarter section) in size, it is recommended that 160 acres be used for the upper limit of the rational method.

4.2.2 Runoff Modeling on Large Drainage Areas

While the rational method is recommended for use on drainage areas up to 160 acres, an alternative runoff modeling method is recommended for larger areas, which includes use of the curve numbers method or infiltration equations for determining net runoff and unit hydrographs or hydraulic runoff methods for computing discharges and hydrographs.

Determining Net Runoff

The rational method lumps the processes of initial abstraction and infiltration, including the variation of infiltration with antecedent moisture conditions, temporal and spatial rainfall patterns, and differing soil and land use types, into a single coefficient. Temporal rainfall patterns are reduced to a single value of intensity related to the time of concentration of the drainage area. While these simplifications are reasonable and work well for small drainage areas, it is equally unreasonable to try to condense into two variables for the complexities of a large, heterogeneous drainage area subjectèd to a temporally and spatially varied "real" storm. For larger drainage areas methods such as the SCS curve number method or methods using infiltration equations such as Horton's or Green-Ampt are necessary.

Curve number methods take into consideration antecedent moisture conditions, soil types and land use which are important factors controlling runoff. The SCS curve number method is currently the most widely used method in Maricopa County for larger drainage areas.

Infiltration equations require parameters that define the rate of infiltration or precipitation loss during a rainfall event. Typical parameters might include an initial loss rate, a final loss rate and a function defining the change in loss rate, which may occur either as a function of time or as a function of accumulated precipitation. Infiltration equations are not widely used in Maricopa County at this time.

In comparing the two methods, the SCS curve number method is more empirical while the use of infiltration or loss equations has a more theoretical basis. Both methods can be calibrated to reflect the hydrologic conditions in Maricopa County, producing acceptable results. However, as the curve number method is the most familiar to local engineers and hydrologists at the present time, it is recommended that the SCS curve number method be used for determining net runoff. It is also recommended that a uniform procedure be established to address selection of curve number and antecedent moisture conditions along with verifying the terms in the SCS loss rate function. The adequacy of the curve number method should be reassessed when calibration data becomes available, and at that point the decision should be made as to whether another method for determining net runoff would be more applicable.

Discharge and Hydrograph Determination

Peak discharges and hydrographs may be determined for larger drainage areas by using unit hydrographs, (including both synthetic unit hydrographs and instantaneous unit hydrographs) or by hydraulic runoff methods.

All unit hydrographs are based on the concept of routing runoff through a drainage area, although this is most explicit in the instantaneous unit hydrographs. The Santa Barbara Urban Hydrograph is a simple instantaneous unit hydrograph that simulates runoff routing with a single linear reservoir. Use of the single routing does not adequately account for storage in drainage areas larger than about 3 square miles. Hydrographs simulated for larger areas appear as a sharp spike (like a flash flood) rather than a longer duration, well rounded hydrograph and thus over estimate peak discharge. Since it is desirable to model drainage areas in Maricopa County, which are larger than about 3 square miles, this method would not be satisfactory. More involved instantaneous unit hydrographs (such as the Clark Unit Hydrograph, which may be thought of as a series of linear reservoirs) are applicable to larger areas. For areas of about 160 acres to 10 or more square miles, they do not provide significantly better results than ordinary unit hydrographs, although they are more complex conceptually. Their use is typically restricted to detailed study of very large basins with good stream flow records for calibration.

Unit hydrographs such as Snyder's unit hydrograph and the SCS dimensionless unit hydrograph are commonly used on large drainage areas of the sizes mentioned above. Currently, the SCS hydrograph is the most widely used method in Maricopa County for large drainage areas (including the ADOT methods, which are adapted from the SCS hydrograph method). Dimensionless unit hydrographs are a subset of synthetic unit hydrographs, developed based on averages of many hydrographs from gaged areas.

Hydraulic runoff methods are an alternative to unit hydrographs. They simulate flow on overland flow planes and in channels with the use of Manning's equation (or a similar one) and can model runoff in detail. The ability to model runoff in detail is very attractive, but in practice this also means results may vary significantly with the level of detail used. Hydraulic runoff modeling requires different Manning n values for overland and open channel flow (overland flow occurs at low Reynolds numbers, therefore, higher resistance coefficients are required than for the more turbulent open channel flow). Thus, results will vary depending upon whether a drainage area is modeled as mostly overland flow or mostly channelized flow. Hydraulic runoff methods can be successfully used by an experienced engineer or hydrologist, but for general use, unit hydrographs are simpler, may be used more consistently, and can give equally reliable results when calibrated.

It is recommended, therefore, that unit hydrographs be used for modeling runoff on drainage areas greater than 160 acres in size in Maricopa County. Initially a dimensionless unit hydrograph, such as the one used by SCS may be used. It should subsequently be calibrated for local conditions, resulting in a Maricopa County Unit Hydrograph Procedure. It is also recommended that this procedure be made available as a computer program for microcomputers and mainframe computers. This will help establish uniform use of the procedure and aid revision and updating of the procedure as it is calibrated.

4.3 EVALUATION OF HYDROGRAPH ROUTING METHODS

The selection of a method for hydrograph routing depends on whether it will be used for an open channel or for a reservoir and on the detail needed. For reservoirs, hydrographs should be routed by either level-pool routing (Puls method) or by the modified Puls method (only technique varies between the two methods, results do not). For open channels, different methods are recommended for the different size categories of drainage areas.

4.3.1 Routing Hydrographs From Small Drainage Areas

The rational method has been recommended for estimating peak discharges on drainage areas up to 160 acres. The technique for routing triangular hydrographs through open channels should be relatively simple, corresponding with the relatively simple methods used in deriving them.

Currently in Maricopa County, direct translation of hydrographs based on average travel time is the most widely used method for hydrograph routing. Direct translation is slightly conservative as peak discharges are not attenuated, but for flows from small drainage areas this is not usually significant. It is also consistent with use of the rational method. Therefore, it is recommended that direct translation be used for routing hydrographs from small drainage areas and that uniform procedures be established. The hydrograph routing method for large drainage areas should be allowed to be used for smaller areas but not required.

4.3.2 Routing Hydrographs From Large Drainage Areas

As the rational method is not considered adequate for use on larger drainage areas, neither can direct translation be considered adequate for routing hydrographs from larger areas. For routing these hydrographs through open channels, either hydrologic (storage) or hydraulic routing is recommended.

If storage routing is used, a variable storage-discharge method should be used, such as the Muskingum method or the working value method. For hydraulic routing, the kinematic wave method is typically used. Both methods require information on channel geometry and roughness coefficients. The major difference is in entering the parameters either directly as hydraulic parameters (kinematic wave method) or indirectly as storage coefficients (storage methods). The direct use of channel characteristics causes the kinematic wave method to be conceptually simpler to model (i.e., the concept of storage coefficients is not required). Although its use requires more calculations, it is recommended that the kinematic wave method be used for routing hydrographs from large drainage areas. Standard procedures should be established for its use, and it should be included in the unit hydrograph procedure when it is produced as a computer program.

4.4 SUMMARY OF RECOMMENDATIONS

The recommendations for determining runoff and routing hydrographs, for both small and large drainage areas, are summarized as follows:

<u>For areas up to 160 acres:</u>

- The rational method be used for computing peak discharges.
- Uniform methods of determining runoff coefficients and time of concentration that reflect conditions in Maricopa County be established.
- Uniform procedures for constructing triangular hydrographs be established. The hydrographs should be routed by direct translation.

<u>For areas greater than 160 acres:</u>

- Net runoff be determined by the SCS curve number method with uniform curve numbers established to provide for consistent results.
- Unit hydrograph be used for synthesizing hydrographs. The SCS dimensionless unit hydrograph may be used until the Maricopa County Unit Hydrograph is developed.
- The kinematic wave method be used for routing hydrographs.
- A hydrologic data collection program be implemented to aid in the calibration of curve numbers and hydrograph parameters.
- A hydrologic computer program, be developed for the Maricopa County Unit Hydrograph Procedure. This will assist in prompting widespread use of the standardized methods and will facilitate changes as the methods are calibrated.

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