PC-HYDRO V 5
Pima County Hydrology Procedures

A Computer Program for Predicting Peak Discharges of Surface Runoff from Small Semi-Arid Watersheds in Pima County, Arizona

PC-HYDRO User Guide

prepared for:

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i. Preface

The PC-HYDRO computer program, version 5.x, will calculate flood peaks of varying frequencies for use in the analysis and design of natural and constructed drainage systems located in unincorporated Pima County, Arizona. The program is based on the Pima County Hydrology Procedures described in the *Hydrology Manual for Engineering Design and Flood Plain Management within Pima County, Arizona* (1977 and 1979, Pima County Department of Transportation and Flood Control District). This User Guide is intended to replace the previous Hydrology Manual.

This User Guide will help novice and experienced users prepare input, understand the software methodology, and interpret the output. A brief step-by-step procedure for inputting the required hydrologic parameters in the Windows environment is provided. This guide also documents the computational portion of the program and describes the detailed input and output.

Much of the procedural information provided in this User Guide may be referenced by the context-sensitive Help button found on the toolbar of each Data Input Form.

PC-HYDRO Version 5.x is improved over previous versions of this software, through inclusion of the following features:

- The availability from, and endorsement of, the software by the Pima County Regional Flood Control District (PCRFCD).

- The addition of context-sensitive Help files integrated into the toolbar of each Data Input Form.

- The availability of this User Guide describing the acceptable use of PC-HYDRO.

- The addition of rainfall intensity-duration-frequency data from NOAA Atlas 14, and the ability to quickly and accurately input these upper 90% confidence limit values by entering the latitude and longitude of the centroid of the watershed under investigation.

- The ability to produce and export hydrograph output as well as peak discharge estimates. The synthetic hydrograph method is the same as used in the Stormwater Detention/ Retention Manual (PCDOT&FCD, 1987).

- The addition of Hydrologic Soils Group maps for quick reference.

Please report any computational or other problems with this software to the Pima County Regional Flood Control District (520-243-1800).

ii. Acknowledgments

The PC-HYDRO program and User Guide were developed and written by the following:

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Steve Dolan, Chief Hydrologist, PCRFCD, Planning and Development Division
Jerry Curless, PE, former Division Manager, PCRFCD, Planning and Development Division Michael E. Zeller, PE, PH, Tetra Tech was the developer of the method and provided comments on this release.

This work was presented to the 12-member Flood Control District Advisory Committee (FCDAC), which includes five members appointed by the Pima County Flood Control Board (one for each Board member), three representatives from the City of Tucson, and one representative each from the City of South Tucson, the towns of Marana, Oro Valley and Sahuarita. One position, in an ex-officio capacity, is available for appointment by the Tohono O'odham Nation. Voting Members of the 2006 FCDAC include:

District 1 (Supervisor Ann Day)	Doug Shakel
District 2 (Supervisor Ramón Valadez)	Vacant
District 3 (Supervisor Sharon Bronson)	Scott Altherr, PE, CFM
District 4 (Supervisor Ray Carroll)	Paul Cella, PE
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City of South Tucson	Richard Salaz
Town of Marana	Jennifer Christelman, Chairman
Town of Oro Valley	Ralph Stein
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iii PC-HYDRO Background

The original computational procedure for the Pima County Hydrology Method was developed by Michael E. Zeller PE, PH while employed by the District, and presented with examples in the *Hydrology Manual for Engineering Design and Floodplain Management within Pima County, Arizona* (Pima County Department of Transportation and Flood Control District, Tucson, Arizona). The manual was first published in 1977, and later republished in 1979 with minor corrections and additions. Mr. Zeller developed and authored this semi-empirical rainfall-runoff model, which has been widely used and accepted in Pima County for predicting flood peaks from ungaged watersheds under natural and developed hydrologic conditions. In addition, this hydrologic method has been approved by FEMA for calculating regulatory flood peaks for use in unincorporated Pima County.

Mr. Zeller also modified this floodpeak prediction procedure for use within the City of Tucson, and a description of this modified procedure was distributed in 1982 in a letter from the acting City Engineer, titled *Shortened Flood Peak Estimator Procedure*. This City procedure underwent further modifications that generally resulted in relatively smaller flood peaks, and was republished in 1989 and again in 1998 as part of the City of Tucson's *Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona* (City of Tucson, Department of Transportation, 1989). More recently, the PCRFCD incorporated the newer rainfall intensity-duration-frequency data from NOAA Atlas 14, which superseded NOAA Atlas 2 used in the original manual.

When first developed, calculations based on the Pima County Hydrology Procedures, and later by the City of Tucson's Shortened Flood Peak Estimator Procedure, were typically done by hand, or with the aide of simple hand-held programmable calculators. In order to overcome the need for by-hand calculations, the PC-HYDRO program was written in 1992 by Robert J. Smolinsky, PE for use as a computational tool by Arroyo Engineering. This original version of the software was freely distributed and widely used throughout the local engineering community. Arroyo Engineering was later contracted by the Pima County Regional Flood Control District to improve the computational capabilities of this software, as well as to expand its availability. This User Guide has been written for this Windows-based PC-HYDRO program.

A User Guide for PC-HYDRO

1.0 Introduction

This chapter describes, in general terms, the application of the PC-HYDRO program to calculate flood peaks using the Pima County Hydrology Procedures. Items covered include the program purpose, use and origin, conditions of use, software availability and program operation and system requirements. Succeeding chapters of this guide give detailed descriptions of the program and provide information for preparing input and interpreting output. The appendixes contain a Quick Start Guide and sample calculations representing the range of typical applications.

1.1 Program Purpose, Use, and Origin

PC-HYDRO is a Windows-based computer program that predicts peak discharges from surface runoff on small semiarid watersheds located in Pima County, Arizona. In general, PC-HYDRO is a computer program that will enable the user to systematically calculate flood peaks and hydrographs of varying frequencies for urban and non-urban watersheds located in Pima County, provided that they are less than or equal to 10 square miles, have a Time of Concentration of less than 180 minutes, and are not controlled by flood-control reservoirs or basins.

This program is intended for use by engineers, hydrologists, and floodplain managers in the analysis and design of both natural and constructed drainage systems. The computational procedure employed by this computer program is known as the Pima County Hydrology Procedures, and were described in the *Hydrology Manual for Engineering Design and Flood Plain Management within Pima County, Arizona* (1977 and 1979; Zeller, M.E., Pima County Department of Transportation and Flood Control District). The PC-HYDRO computer program was originally written in 1992 by Robert J. Smolinsky PE, and was widely available and distributed by Arroyo Engineering. More recently, the program was modified to accept rainfall intensity-depth-duration data from NOAA Atlas 14 upper 90% rainfall.

1.2 Conditions of Use

The Pima County Regional Flood Control District grants to the user the rights to install PC-HYDRO, and to use, copy and/or distribute copies of this software to other users, subject to the strict compliance with the Terms and Conditions of Use given in Appendix A, including the Waiver of Liability, Limitations of Liability, Indemnity, and the voluntary Assention of all Terms and Conditions of Use.

The software code has been written so that it requires acceptance of these Terms and Conditions of Use in order to operate.

1.3 Software Availability

This User Guide and executable copies of the PC-HYDRO V5.x software (or any revised versions of these materials) are available from the Pima County Regional Flood Control District, in Tucson, Arizona.

1.4 Program Operation and System Requirements

PC-HYDRO was developed in Microsoft Visual Basic 5.0, and is intended to be installed on an IBM PC or compatible, running with Microsoft Windows 98/2000/ME/XP or above. It is recommended that the latest service pack for each operating system be installed. A viewable version of this User Guide, as well as the Help pull-down screens within the computer program itself, require Adobe Reader 6.0 or above. A brief Program Installation Guide can be found in Appendix B.

1.5 Program Quick Start Guide

A Quick Start Guide can be found in Appendix C for experienced users interested in immediately applying this latest version of PC-HYDRO.

1.6 Figures and Tables

Selected Figures and Tables referenced in this User Guide have been placed in Appendix D for reference. Some of these figures also appear in the text.

1.7 Sample Calculations

Appendix F of this User Guide contains examples of six watersheds in Pima County illustrating the typical application of PC-HYDRO within its range of applicability.

2.0 Program Description

This chapter describes the computational basis and assumptions used in the PC-HYDRO program. Items covered include a discussion of computational methodology, as well as the equations used for calculating the watershed Time of Concentration and rainfall intensity.

The succeeding chapters of this guide give detailed descriptions of how to prepare input, as well as for interpreting program output.

2.1 Storm and Flood Frequency Criteria

In general, the one percent annual chance flood, or 100-year flood, is used as the federal, state, and local standard for the design of new construction within floodprone areas. However, sometimes there is a need to determine the area at risk of flooding in the 500-year event for locating critical facilities like hospitals or fire stations.

Additionally, the more frequent flood events are often needed to demonstrate the efficacy of stormwater detention basins required as a condition of new development. Peak discharges for floods smaller or more frequent than a 100-year flood, as well as the 100 and 500-year event can be calculated directly by the program.

2.2 General Methodology

The Pima County Hydrology Procedures are used to predict flood peaks from rural and urban watersheds of less than 10 square miles in Pima County. It is a semi-empirical method in which a peak discharge for a given flood frequency or return interval is calculated as the product of a runoff coefficient, rainfall intensity, and drainage area. This method is similar to the Rational Formula, but avoids one of the major pitfalls of the Rational Formula by incorporating a runoff to rainfall ratio that increases with increasing rainfall. In addition, the Pima County Hydrology Procedures calculates rainfall intensity by computing the watershed Time of Concentration using an empirical equation that relates Time of Concentration to the physical characteristics of the watershed and rainfall intensity.

This analytical approach is believed to be unique to Pima County, and the selection and evolution of this semi-empirical rainfall-runoff model was based on flood-frequency data for the Tucson area available in the 1970s when the method was first developed. The conceptual framework came from existing USDA methods and a paper by Rostomov (1967; as described by Zeller, personal communication, 2006).

2.3 Assumptions in the Pima County Hydrology Procedures

The Pima County Hydrology Procedures are essentially small-watershed hydrology methods subject to the following typical assumptions (adapted from Ponce, 1989):

1. Rainfall is uniformly distributed over the entire watershed;
2. Rainfall occurs at a uniform intensity for a storm duration at least equal to the Time of Concentration;
3. Peak rate of runoff is proportional to rainfall intensity or rainfall depth averaged over a time period equal to the Time of Concentration;
4. The return period of the runoff event is the same as the return period of the precipitation event; and,
5. Channel storage processes or diffusion are negligible.

Some of the general weaknesses of small-watershed hydrology models with the form of the Rational Formula are (from Ponce, 1989):

- Calculations reflect only the peak discharge rate, and give no indication of the volume or the time distribution of the runoff.
- Estimation of Time of Concentration is critical to the application of the method. However, in practice, the Time of Concentration is not a fixed value, but will vary with rainfall intensity and runoff rate.
- There are a range of possible runoff coefficients for each surface condition. The runoff coefficient is a lumped-parameter that combines many watershed variables into this one highly-variable parameter.

Because Time of Concentration in the Pima County Hydrology Procedure varies with watershed characteristics and rainfall, it avoids some of the weaknesses of Rational Formula models. Furthermore, since PC-HYDRO produces a dimensionless hydrograph based on methods of Hickok and others (1959), runoff volume can be estimated. However, the Pima County Hydrology Procedure is a simplification of a complex hydrologic process. Still, the method is considered sufficiently accurate for runoff estimation.

If the five assumptions listed above can be shown to remain substantially true, the Pima County Hydrology Procedures can be used for watersheds up to 10 square miles. However, in general, the assumptions of small watershed hydrology models, like the Pima County Hydrology Procedures, tend to be valid for watersheds up to about 1 square mile (Ponce, 1989). Therefore, the user should understand the inherent limitations of the Pima County Hydrology Procedures prior to application, and consideration should be given to the possibility that other more sophisticated rainfall-runoff models may be better suited when faced with moderately large or nonhomogeneous watersheds. It is up to the user to decide if other hydrology methods are more appropriate. However, if a user chooses to use an alternative hydrologic model, the method must be approved by the PCRFCD prior to making project submittals.

2.4 Computational Basis of the Pima County Hydrology Procedures

The Pima County Hydrology Procedures, as presented in this User Guide, are limited to:

- The prediction of flood peaks from rural and urban watersheds of less than 10 square miles;
- Watersheds that have a Time of Concentration less than 180 minutes; and,
- Watersheds that are not influenced by regional flood-control reservoirs or basins.

It is a semi-empirical method similar to the Rational Formula in which peak discharges for a given flood frequency are calculated as the product of drainage area and runoff supply rate.

When selecting input values for PC-HYDRO, such as land use, vegetation density, and the amount of impervious cover, the user shall assume existing watershed conditions if stormwater detention will be required as a condition of future development within the subject watershed. Otherwise the user shall assume future conditions based on allowable Land Use Intensities given in the Pima County Comprehensive Plan, or other reliable sources of information. Likewise, regardless of whether or not stormwater detention/retention will be required as a condition of future land development, the user shall assume future conditions throughout the basin based on allowable Land Use Intensities given in the Pima County Comprehensive Plan when selecting values for the Basin Factor.

2.4.1 Calculating Peak Discharge

The Pima County Hydrology Procedures describe the relationship between peak runoff rate and watershed characteristics, rainfall intensity, and drainage area. The basic equation of the Pima County Hydrology Procedures is:

$$Q_p = 1.008\ q\ A \qquad \text{\{Equation 1\}}$$

Where,

Q_p is the calculated peak discharge, cubic feet per second or cfs;
1.008 is a factor for converting acre-in/hour to ft^3/sec;
(1 ac-in/hr x 43,560 ft3/ac-ft x 1 hr/3600 sec x 1 ft/12 inches = 1.008 cfs);
q is the runoff supply rate, in/hr, at the watershed Time of Concentration; and,
A is the watershed area above the outlet or concentration point, acres.

2.4.2 Runoff Supply Rate

The runoff supply rate, q, is a function of rainfall intensity and watershed characteristics (soil type, vegetative cover, flow distance, slope, channel roughness, and degree of urban development), and it is expressed as:

$$q = C_w \, i \qquad \text{\{Equation 2\}}$$

Where,

- q is the runoff supply rate, in/hr, at the watershed Time of Concentration;
- C_w is the Runoff Coefficient or the area-weighted ratio of runoff to rainfall. It is dimensionless, and is a function of the basic Natural Resource Conservation Service (NRCS)-SCS Curve Number and the 1-hour rainfall depth for a given storm frequency; and,
- i is the rainfall intensity, in/hr, calculated at the watershed Time of Concentration for the given discharge frequency.

2.4.3 Runoff Coefficient (C_w)

The Runoff Coefficient (C_w) is a dimensionless ratio intended to indicate the amount of runoff generated by a watershed for a given average rainfall intensity. It is a function of the SCS Curve Number, which in turn is a function of Soil Type, Vegetation Cover Type and Density, Impervious Cover, and the 1-hour rainfall depth for a given storm frequency. For each subarea, a weighted runoff coefficient is calculated.

Calculating representative values for C_w requires determining the appropriate Hydrologic Soils Group (HSG) from NRCS-SCS soil maps, selecting a base Curve Number (CN) based on the HSG and land cover, and then adjusting those base values to account for the lower infiltration rates (and higher effective C_w values). The CN adjustment procedure in the Pima County Hydrology Procedures was adapted from research conducted at the USDA-ARS Walnut Gulch experimental watershed near Tombstone, which showed that, for the same area, Curve Numbers increased with increasing rainfall depth and intensity (Zeller, personal communication. 2006). The Pima County Hydrology Procedures assumes that high intensity, short duration storms result in raindrop impacts causing the surface of soils to seal up, thus reducing infiltration. This phenomenon is referred to as the ‘Caliche Effect’.

In general, the procedure used to calculate the area-weighted C_w involves:

- Identifying each major soil type and determining the appropriate Hydrologic Soil Group.
- Identifying the land-use category and condition.
- Determining the base Curve Number for each soil type/land use combination (per ADOT, 1968).
- Adjusting the base Curve Numbers to account for the ‘Caliche Effect’ by using the one-hour rainfall depth for the particular design flood frequency under investigation.
- Calculating the area-weighted average C_w for each soil type.

The model sensitivity analysis presented in this User Guide demonstrated that CN was the most-sensitive parameter in the PC-HYDRO program for the scenario used. However, some parameters, such as the Basin Factor, may vary by a greater percentage. Therefore, care must be given to the selection of the base CN for use in the program. The NRCS has published tables with Curve Numbers for desert conditions (NRCS, 1986). However, the method for estimating the base CN in the Pima County Hydrology Procedures was based on earlier data used by the Arizona Department of Transportation (ADOT, 1968). These differ substantially from the more recent tables. Therefore, the ADOT 1968 Curve Numbers given in this User Guide shall be the only ones used to calculate flood peaks using the PC-HYDRO program.

2.4.3.1 NRCS-SCS Soil Types and Hydrologic Soil Group Classification

The soil types and their representative Hydrologic Soil Group are found by referring to soils maps of the study area, such as the *Soil Survey for Eastern Pima County* (NRCS, 2002) and the *Soil Survey for the Tucson-Avra Valley Area* (SCS, 1972). These documents can be obtained from the Tucson office of the Natural Resources Conservation Service, NRCS, or on the internet (for example, http://soildatamart.nrcs.usda.gov/ or http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx).

Each soil series is classified into one of four hydrologic soil groups (HSG) according to their minimum infiltration rate obtained for bare soil after prolonged wetting (SCS, 1985). Those soil groups are briefly defined as:

Type A. (Low runoff potential). These soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission (8 to12 mm/hr), and are generally described as sand, loamy sand, and sandy loam.

Type B. (Moderately low runoff potential). These soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well drained to well drained, soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission (4 to 8 mm/hr), and are generally described as silty loam, and loam.

Type C. (Moderately high runoff potential). These soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission (1 to 4 mm/hr), and are generally described as sandy clay loam.

Type D. (High runoff potential). These soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have high swelling potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission (0 to 1 mm/hr), and are generally described as clay loam, and silty clay loam.

For the purposes of calculating flood peaks using PC-HYDRO, it is to be conservatively assumed there are no Type A soils within the watershed under investigation, and if any areas have been mapped as Type A, then these shall be included with those mapped as Type B.

2.4.3.2 Hydrologic Soils Group Maps

NRCS soil maps are intended to separate the landscape into segments that have similar use and management requirements, which means that each individual soil series is not mapped separately. Soil mapping units may contain several soil series. A mapping unit is named for the 'major soils' in the mapping unit. Mapping units may also include 'minor soils,' which are often similar to the major soils, but occasionally contrast. The percentage of each major soil in a mapping unit is provided in the survey, but the percentage of each minor soil is not. Each major or minor soil has an associated HSG.

In order to aid in estimating CNs, the PCRFCD prepared soils maps of the entire county that estimate the portion of each HSG in a mapping unit based on the major soils only. In most mapping units, the major soils fall into a single HSG. However, when a mapping unit contains major soils with more than one HSG, each was used in proportion to estimate the HSGs of the mapping unit. For example, the Altar-Sasabe soil mapping unit contains 50% Altar Soils, which are HSG B, and 30% Sasabe Soils, which are HSG C. The remaining 20% of the mapping unit is composed of minor soils. For the purposes of estimating the HSG of the mapping unit, the minor soils were neglected, so that the PCRFCD map shows the mapping unit to be 37.5% C and 62.5% B.

The PCRFCD has prepared HSG maps of the entire county by providing the HSG of the major soils in the following Soil Surveys (available from the Soils Data Mart):

- Soil Survey 646: Organ Pipe Cactus National Monument, Arizona.
- Soil Survey 653: Gila Bend-Ajo Area, Arizona, Parts of Maricopa and Pima Counties.
- Soil Survey 667: Santa Cruz and Parts of Cochise and Pima Counties, Arizona.
- Soil Survey 668: Tucson-Avra Valley Area, Arizona.
- Soil Survey 669: Pima County, Arizona, Eastern Part.
- Soil Survey 703: Tohono O'Odham Nation, Arizona, Parts of Maricopa, Pima and Pinal Counties.
- Arizona General Soil Map for the Colorado National Forest and other unmapped areas.

Using the major soils, digital maps were prepared at the township scale, and are included on the DVD accompanying the User Guide. An example map is as follows (pdf version):

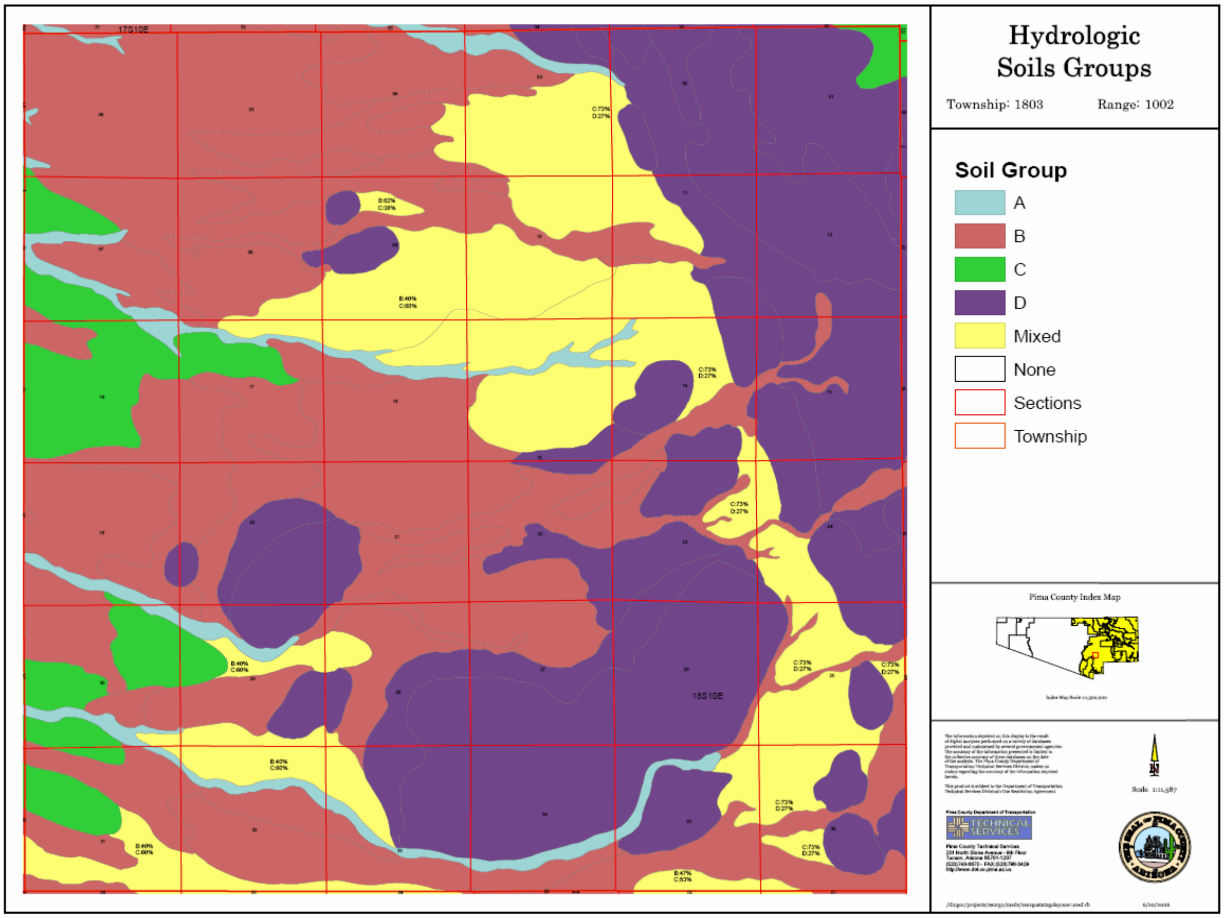


Figure 1 – Sample Hydrologic Soils Group Map

Each map is available in Adobe Acrobat Reader files, TIF, and Arcview shape files. TIF World files are also provided and soil maps are available on the Pima County Map Guide Site. These maps include spatial coordinates that allow them to be pulled into CAD or GIS programs. For mixed HSG mapping units (shown in yellow), the percentage of each HSG is provided on the map.

While these maps are intended to aid in estimating the HSG and associated CN, the user may choose to obtain the appropriate soil survey in order to determine if there are significant contrasting minor soils on the watershed that would impact the selection of a CN.

2.4.3.3 Hydrologic Cover Types

The Hydrologic Cover Types refer to the vegetation cover of the watershed under investigation. The SCS has classified Hydrologic Cover Types into the following groups (ADOT, 1968, Turner, 1995):

Desert Brush: Desert Brush includes common-named Sonoran Desert plants such as Velvet Mesquite, Foothills Palo Verde, Catclaw, Acacia, Creosote bush, Bursage, and

Prickly Pear, Cholla, and Saguaro cactii. Desert Brush is typical of lower elevations and low annual rainfall. Maximum elevations generally do not exceed 4000 feet.

Herbaceous: Herbaceous Cover includes short desert grasses with some brush, and is typical of intermediate elevations with higher annual rainfall than desert areas. Elevations generally range from 1500 feet to 5000 feet.

Mountain Brush: Mountain brush includes mixtures of oak, conifers, Aspen, and Mexican Manzanita, and is typical of intermediate elevations with higher annual rainfall than herbaceous areas. Elevations generally range from 4000 feet to 7000 feet.

Juniper-Grass: Juniper areas are mixture of Juniper and other woody plants, with varying amounts grass cover, and usually have a higher cover density than desert grasses because of higher annual precipitation, typical of higher elevations. Elevations generally range from a minimum of 6500 feet to the tops of the highest peaks at about 9500 feet.

Ponderosa Pine: Ponderosa Pine forests are typical of high elevations and relatively high annual precipitation. These forests are most common near the highest mountain tops.

Urban Lawns: Urban Lawns include cultivated grasses, shrubs and trees, plus any other types of vegetation not normally indigenous to the Sonoran Desert, which are used for landscape purposes within residential urban areas. Generally found at elevations below 4,000 feet.

2.4.3.4 Vegetative Cover Density

The Vegetative Cover Density is the relative amount of the ground surface covered by vegetation, including the crown canopy of live plants and litter, and is measured in percent. A visual estimate of the Vegetative Cover Density is often sufficient for the purposes of calculating flood peaks using PC-HYDRO. However, field techniques for estimating Vegetation Cover Density are presented in Appendix E. These are taken directly from (ADOT, 1968), which is also the source of the CN estimating techniques used in the Pima County Hydrology Procedures.

The SCS has classified Vegetative Cover Density of arid and semiarid rangelands into three broad ranges (ADOT, 1968):

- Poor 20 % or less vegetative cover
- Fair 20 % to 40 % vegetative cover
- Good 40 % or more vegetative cover

In general, the maximum Cover Density of Desert Brush in Pima County should not exceed 40%, and ***in the absence of reliable information concerning a particular area, it is recommended that a value of 20% be used***.

2.4.3.5 SCS Curve Number

In general, the base Curve Number shall be found by referring to the graph of Hydrologic Soil-Cover Complexes and Associated Curve Numbers found on Figure 2 and Appendix D (ADOT, 1968).

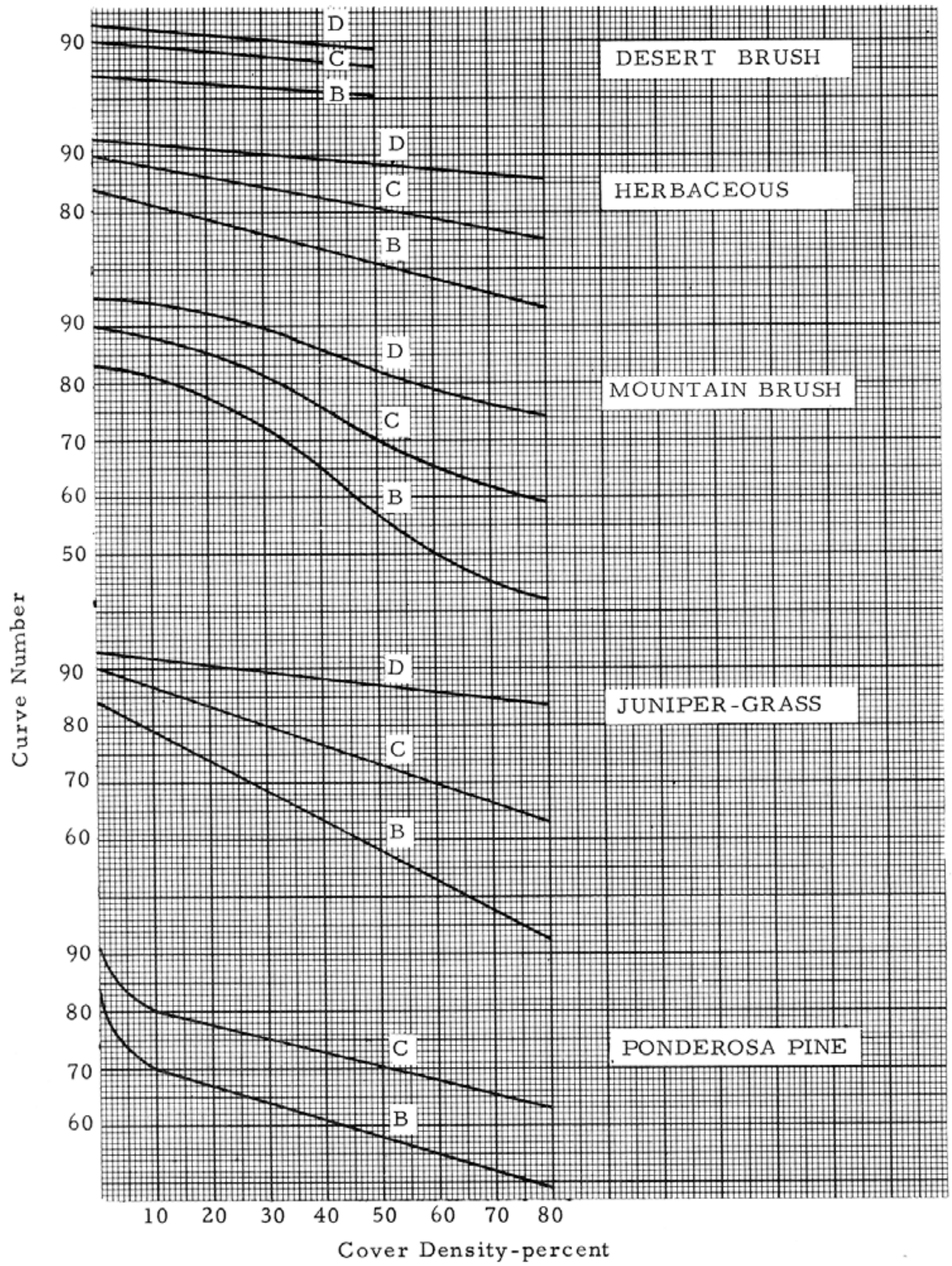


Figure 2 – Chart for Estimating Base Curve Numbers

Alternatively, Curve Numbers for Desert Brush can also be found below in Table 1 for varying Vegetative Cover Densities. As mentioned previously, these tabulated values differ from Curve Numbers presented in current NRCS documents (NRCS, 1986). Similarly, Curve Numbers for Urban Lawns can be found in Table 2. These values were developed from local runoff data for short-duration storms over urban areas with average antecedent moisture conditions. All impervious areas are assigned a base Curve Number of 99 automatically by the program. Copies of Tables 1 and 2 can also be found in Appendix D of this User Guide.

Table 1 – Summary of SCS Curve Numbers for Desert Brush

Hydrologic Soil Types	Vegetative Cover Density			
	10%	***20%****	30%	40%
Types A and B	85	***83***	82	81
Type C	89	***88***	87	86
Type D	92	***91***	90	89

Table 2 – Summary of SCS Curve Numbers for Urban Lawns

Hydrologic Soil Types	Vegetative Cover Density		
	Poor < 30% Coverage	***Average**** ***30% to 60% Coverage***	Excellent > 60% Coverage
Types A and B	83	***79***	74
Type C	88	***86***	83
Type D	91	***90***	87

**** Recommended for average or default conditions***
(PCDOT&FCD, 1979).

2.4.3.6 Estimation of Impervious Cover

Impervious cover refers to the relative amount of the ground surface covered by impervious surfaces, including natural rock outcrops, paved roads, parking lots, and rooftops. It is measured in percent. A visual estimate of the Impervious Cover is often sufficient for the purposes of calculating flood peaks using PC-HYDRO.

Tables 3 provides a list of typical minimum, average, and maximum values of impervious cover for varying development types, and were based on the assumption that paved streets are adjacent to at least one side of the developed lot.

As a general rule, the values indicated as being "average" for the type of development anticipated should be utilized. Adjustments to these average values should only be made on the basis of proposed subdivision plats and/or area plans, neighborhood plans, and existing development (PCDOT&FCD, 1979).

Furthermore, when selecting representative values for impervious cover, the user shall assume existing watershed conditions if stormwater detention will be required as a condition of future development within the entire watershed, otherwise, the user shall assume future conditions based on allowable Land Use Intensities given in the Pima County Comprehensive Plan, or other reliable sources of information.

Table 3 – Summary of Approximate Impervious Cover Percentages for Various Land Development Types

Development Type		Impervious Cover Percentage		
		Minimum	Average	Maximum
Rural and Suburban:				
a.	Less than 1 house/acre	5 %	10 %	20 %
b.	1 house/acre	15 %	20 %	25 %
c.	2 houses/acre	25 %	30 %	35 %
Light to Moderate Urbanization:				
a.	3 houses/acre	30 %	35 %	40 %
b.	4 houses/acre (detached)	35 %	40 %	45 %
c.	5 houses/acre (detached)	45 %	50 %	55 %
Highly Urbanized:				
a.	Multiple Dwellings, 4 units/acre or more	50 %	65 %	90 %
c.	Light Industrial and Commercial	50 %	65 %-75%	80 %
d.	Heavy Industrial and Commercial	80 %	85 %-95 %	100 %

(PCDOT&FCD, 1979)

2.4.5 Rainfall Intensity

Rainfall intensity (i, typically in units of inch/hr) for a particular location, is a function of geographic location and the design storm frequency or return interval. For the larger, less frequent, storms the precipitation intensity for a given storm duration increases. Similarly, the longer the duration of the storm, the lower the storm average precipitation intensity. The relationships between these three factors (storm intensity, storm duration, and storm return interval or frequency), can be represented by a family of curves called intensity-duration-frequency curves, or IDF curves, which can be determined by analysis of storms for a particular rainfall gaging station, or by the use of standard meteorological atlases, such as NOAA Atlas 2 (1973), or its recent replacement, NOAA Atlas 14 (Vol.1, Version 4.0, Arid Southwest, 2006).

Rainfall intensity, i, when applied to the runoff supply rate equation (Equation 2), is a function of storm duration and frequency. One of the underlying assumptions in the Pima County Hydrology Procedures is that the peak runoff supply rate is proportional to rainfall intensity or rainfall depth averaged over a time-duration equal to the Time of Concentration. Because of this, it is necessary to first calculate the watershed Time of Concentration, and then from this information, calculate by interpolation the rainfall intensity corresponding to this time, using the rainfall intensity-duration-frequency data obtained from NOAA Atlas 14. These calculations are built into the PC-HYDRO program.

The PCRFCD has found that the orographic effects in the NOAA Atlas 14 data are much more pronounced on the low desert than were evident in the NOAA Atlas 2 data. Furthermore, the upper 90% confidence interval of the NOAA Atlas 14 data was shown to result in less relative change in predicted runoff between the NOAA Atlas 2 data than the NOAA Atlas 14 mean value. For this reason, PC-HYDRO uses the upper 90% confidence interval of the NOAA Atlas 14.

2.4.5.1 1-Hour Rainfall Depths

The one-hour rainfall amount, for a particular return interval can be found on the internet (http://dipper.nws.noaa.gov/hdsc/pfds/). For the purposes of calculating flood peaks in Pima County, PC-HYDRO uses by default the 90% Upper Confidence Limits of the intensity-duration-frequency curves, or IDF curves, published in NOAA Atlas 14 (Volume1, Version 4.0, Arid Southwest, 2006). NOAA Atlas 14 supersedes NOAA Atlas 2, used in earlier versions of PC-HYDRO. Flood peaks calculated by PC-HYDRO shall no longer be based on NOAA Atlas 2.

Within PC-HYDRO, the IDF data are automatically determined by typing in the latitude and longitude in decimal degrees (e.g. latitude 32.221007 degrees, longitude 110.971126 degrees @ Stone/Broadway) of the watershed centroid. The coordinates of the watershed centroid is used by PC-HYDRO to query a numerical array consisting of point rainfall values arranged in a grid representing all of Pima County. This array (504 x 168) of rainfall depths was provided by NOAA (ftp://hdsc.nws.noaa.gov/), and has a uniform spacing interval of 0.5-minutes (0.0083 degrees, or about one-half mile). These data encompass all of Pima County, plus enough area beyond the borders of Pima County to include all watersheds contributing runoff to Pima County, except for the upper Santa Cruz River, San Pedro River, Altar Wash, and Cienega Creek watersheds.

The northwest corner of this array of rainfall intensity data represents latitude 32.7917 degrees, longitude 113.3917 degrees, which is located in Section 21, T-11-S, R-10-W, Yuma County. The southeast corner of this array represents approximately latitude 31.4 degrees, longitude 110.4 degrees (located about 75 minutes south and about 180 minutes east of the origin), and is located in Section 27, T-23-S, R-19-E, Cochise County.

Within the database accompanying PC-HYDRO, there is one rainfall intensity array or data set for each storm duration, 5 minutes to 24 hours, and one for each for storm frequency, 2 to 500 years. These 70 data sets can be viewed in *.PCG files (e.g., sa100yr15mau.PCG), where point rainfall values represent 1/1000 inch of precipitation (e.g., 1566 = 1.566 inches). Each data set contains the upper 90% confidence limits of the NOAA 14 rainfall values.

When selecting values for Latitude and Longitude of the watershed centroid, it is usually sufficient to use only three significant figures, because at this latitude, 0.001 degrees is equal to about 300 feet.

2.4.6 Adjusted Curve Number — Caliche Effect

The CN adjustment procedure in the Pima County Hydrology Procedures was adapted from research at the USDA-ARS Walnut Gulch experimental watershed near Tombstone, which showed that, for the same area, Curve Numbers increased with increasing rainfall depth and intensity (Zeller, personal communication. 2006). The Pima County Procedures assumes that high intensity, short duration storms result in raindrop impacts causing the surface of soils to seal up, thus reducing infiltration. This phenomenon is locally referred to as the ‘Caliche Effect’.

The Adjusted Curve Number (CN*) is calculated by substituting the values for the base Curve Number and 1-Hour Rainfall into Equation 3:

$$CN^* = \frac{R1(P_1 - 0.88) + R2}{P_1} \qquad \text{\{Equation 3\}}$$

Where,

- CN* is uniquely defined in the Pima County Hydrology Procedures as the Adjusted Curve Number, and it has a numerical value that is slightly greater than the base Curve Number for a given Hydrologic Soil Type;
- R1 and R2 are adjustment factors obtained from Table D-4, found in Appendix D;
- P_1 is the 1-hour rainfall depth, in inches, for a given return period, and must be greater than 0.88 inches; and,

Applying Equation 3 will generally result in higher CN* for 1-hour rainfall depths greater than about 1.5 inches, and lower CN* for rainfall depths less than about 1.5 inches. This threshold occurs at higher rainfall depths for higher CNs (e.g. 1.7 inches for a Curve Number of 90) and at lower rainfall depths (e.g. 1.4 inches for a Curve Number of 65) for lower CNs.

These effects are illustrated for a typical base Curve Number of 80 in Figure 3. In this graph, the curved line represents the Adjusted Curve Numbers for rainfall depths ranging from 1.0 to 3.5 inches, and were calculated based on a base Curve Number of 80, represented by the horizontal line seen in this same graph.

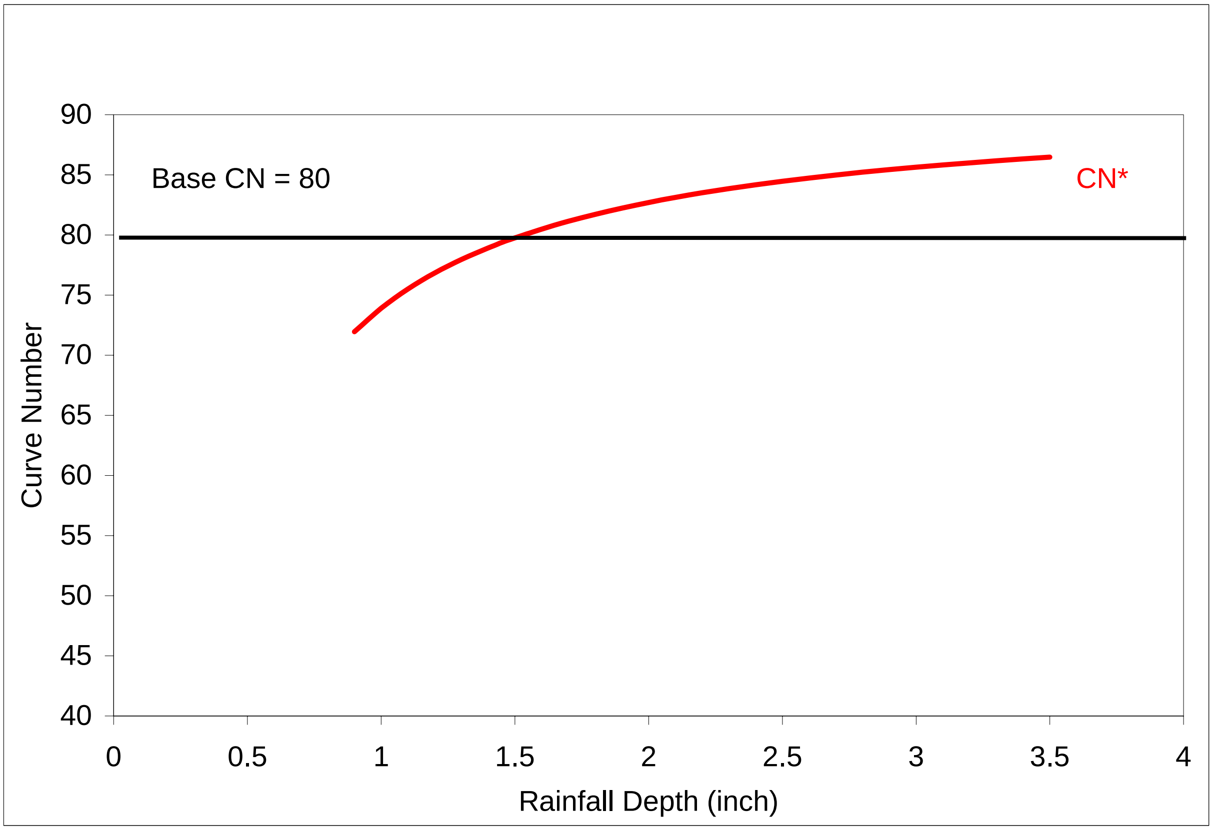


Figure 3 – Graph of Adjusted Curve Numbers for Varying 1-Hour Rainfall Depths as Calculated from an unadjusted base Curve Number of 80

For impervious surfaces, both the base Curve Number and adjusted Curve Number are automatically assigned values of 99 by the program.

The CN* calculated using Equation 3 is usually determined to two significant figures. In addition, if the base Curve Number (CN) determined from Figure 2, (and Appendix D-1), is not a whole number, an interpolation may be made between the values for R1 and R2 when determining the adjusted Curve Number (CN*).

2.4.6.1 Calculating Runoff Coefficients from Adjusted SCS Curve Numbers

The ratio of runoff to rainfall, or Runoff Coefficient, is calculated for each hydrologic soil group, pervious or impervious, using a modification of the familiar SCS Curve Number method for estimating direct runoff from storm rainfall (SCS, 1985),

$$C = \frac{Q}{P_1} \qquad \text{\{Equation 4a\}}$$

$$C = \frac{1}{P_1}\frac{(P_1 - 0.2S)^2}{(P_1 + 0.8S)} \qquad \text{\{Equation 4b\}}$$

Where:

- Q is the total depth of runoff (inches);
- P_1 is the one hour depth of precipitation (inches) for a given frequency;
- 0.8 is empirically derived, and is based on the assumption that initial abstractions are equal to 0.2 S;
- S is the potential abstraction, numerically defined as:

$$S = \frac{1000}{CN*} - 10 \qquad \text{\{Equation 5\}}$$

Where:

- CN* is the adjusted Curve Number.

2.4.6.2 Area-Weighted Runoff Coefficients

When contributing watersheds are nonhomogeneous, then an area-weighted average Runoff Coefficient shall be calculated using Equation 6 (ADOT, 1993):

$$C_w = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i} \qquad \text{\{Equation 6\}}$$

Where,

- C_w is the area-weighted Runoff Coefficient for each hydrologic soil-cover complex within the watershed, including impervious areas;
- C_i is the runoff coefficient for a particular subregion i ; and,
- A_i is the area of the subregion, in consistent units of area, occupied by each adjusted Curve Number.

2.4.7 Time of Concentration

In the context of the Pima County Hydrology Procedures, the Time of Concentration (T_c) represents the time at which all areas of the watershed are contributing runoff to the outlet. It is this storm duration or time that is used to calculate rainfall intensity. In the Pima County Hydrology Procedures it is uniquely defined as:

$$T_c = \frac{n_b}{50} \frac{(L_c L_{ca})^{0.3}}{S_c^{\ 0.4}} q^{-0.4} \qquad \text{\{Equation 7a\}}$$

$$T_c = 0.02 n_b \frac{(L_c L_{ca})^{0.3}}{S_c^{\ 0.4}} \frac{1}{(C_w i)^{0.4}} \qquad \text{\{Equation 7b\}}$$

Where,

- n_b is the watercourse-length-weighted Basin Factor, dimensionless, and is a relative measure of the hydraulic efficiency of the entire watershed, including the hydraulic roughness associated with both the main watercourse, as well as its adjoining upland areas;
- T_c is the calculated Time of Concentration, in hours, and is the theoretical time it takes runoff to travel from the most hydrologically remote location within the watershed to the concentration point;
- L_c is the length of the longest watercourse, in feet, measured from the basin outlet to the watershed divide;
- L_{ca} is the incremental length of the longest watercourse, in feet, measured from the outlet to a point on this longest watercourse located opposite the centroid or center of gravity of the watershed;
- q is the runoff supply rate, in/hr, at the watershed Time of Concentration, and it has been previously defined in Equation 2, above;
- 50 is a conversion factor whose units are $ft^{0.6}$ / $in^{0.4}$ - $hr^{0.6}$; and,
- S_c is the mean watershed slope of the longest watercourse, in ft/ft, as determined by the incremental or uniform slope method defined by Equation 8, described later in this User Guide.

For simple, regularly-shaped basins, the length along the longest watercourse to the watershed centroid, L_{ca} , can be approximated as $L_{ca} = L_c / 2$. However, in watersheds with nonuniform shapes, the L_{ca} value becomes more important in the calculation of the discharge, and this simplification should not be used.

NOAA Atlas 14 provides rainfall intensity of 5 minutes or greater. For that reason, the Time of Concentration for small, short watersheds defaults to 5 minutes, even when it might be less.

2.4.8 Guidelines for Estimating the Basin Factor

A Basin Factor takes into account all physical resistances to flow including laminar surface flow not associated with channel flow. The Basin Factor is mean of the Manning's n-value or roughness coefficient of all principal watercourses within a watershed, and their adjoining upland areas. Though there are many sources for estimating n-values, the Basin Factors in the Pima County method were estimated for local conditions and shall be used.

When estimating the Basin Factor (n_b), of a watershed, field observations of the representative channel locations should be made to determine the overall Basin Factors. In addition, the user should remember to take into account the maximum land development expected to occur within the watershed in the foreseeable future, since urban land use will greatly affect the type of runoff surfaces present within the principal watercourses. This will generally reduce, and in some cases, significantly, the value of its Basin Factor (PCDOT&FCD, 1979).

When estimating the Basin Factor, first estimate the n-value for the watercourse reach or subbasin under investigation, and then add to it the increments of roughness for each condition within the adjoining watershed that increases roughness. These secondary roughness increments are added proportionately based on their relative rate of tributary inflow or contribution. Thus, the Basin Factor for a particular watercourse segment is generally larger in magnitude than the Manning’s n-value estimated for the main channel and overbanks alone. Furthermore, as a quality control check, the Time of Concentration calculated using the selected Basin Factor should be approximately the same as the travel time calculated by summing travel times for each segment of the flowpath.

The Basin Factors presented in Tables 4.1, 4.2 and 4.3 cover a relatively wide range of typical values. In general, these values serve as a guide, however, the values labeled as "normal" for the type of area under investigation shall to be utilized by the user. Adjustments to these "normal" values shall only be made on the basis of the influence of any surface characteristics, which might affect the Time of Concentration of the watershed, provided that supportive written and photographic justification accompany the use of such adjustments, and subject to the approval of the PCRFCD. For a brief explanation of the physical features given in these tables, refer to the explanatory notes following Table 4.3. Copies of Tables 4.1, 4.2, and 4.3 can also be found in Appendix D of this User Guide.

Table 4.1 – Basin Factors for Undeveloped or Developed Areas with No Drainage Improvements

Watershed Type	Mean Slope (ft/ft)	n_b (minimum)	n_b (normal)	n_b (maximum)
Mountain [1]	> 0.03	0.040	0.050	0.060
Foothills [2]	0.01 to 0.04	0.030	0.035	0.040
Valley [3]	< 0.01	0.027	0.030 to 0.040	0.050

Table 4.2 – Basin Factors for Developed Areas with Drainage Improvements (excluding areas of overland flow and shallow sheet flow)

Watershed Type	Development Density	n_b (minimum)	n_b (normal)	n_b (maximum)
Suburban-Foothills [4]	< 1 house/acre	0.029	0.034	0.038
Suburban-Valley [4]	< 1 house/acre	0.027	0.029 to 0.038	0.047
Suburban-Foothills [4]	1-2 houses/acre	0.028	0.032	0.036
Suburban-Valley [4]	1-2 houses/acre	0.026	0.028 to 0.036	0.045
Light to Moderate Urban [5]	3-5 houses/acre (detached)	0.020	0.022	0.025
Highly Urbanized [6]	Apartments to Light Commercial	0.018	0.020	0.022
Commercial and Industrial [7]	Heavy Commercial and Industrial	0.015	0.018	0.020

Table 4.3 – Basin Factors for Overland Flow and Shallow Sheetflow Areas (Restricted Use)

Watershed Type	Watershed Condition	n_b
Paved[8]	all	0.040
Paved and Natural[8]		
	Suburban	0.060
	Light Urban	0.055
	Moderately Urban	0.050
Natural[8]		
	Rough	0.080
	Normal	0.070
	Smooth	0.060

Explanatory Notes:

1. <u>Mountain Areas</u> are mostly undeveloped and are relatively rugged, narrow, and have sharp edges. Similarly, these areas often have relatively steep canyons through which watercourses meander around sharp bends, over large boulders, and through frequent debris obstructions. The ground cover in mountain areas, excluding occasional small areas with rock outcrops, usually includes numerous trees and considerable underbrush.

In addition, there are no significant drainage improvements in undeveloped Mountain Areas.

2. Foothill Areas are mostly undeveloped, and often have rolling terrain with rounded ridges and moderate side slopes. Watercourses typically follow relatively straight, unimproved channels, with some boulders and occasional lodged debris. Ground cover usually includes scattered brush and grasses. In addition, there are no significant drainage improvements in undeveloped Foothill Areas.

3. Valley Areas are mostly undeveloped, and often have comparatively uniform, gentle slopes, as well as surface characteristics in which well defined channelization does not occur. Ground cover usually includes grasses, small shrubs, cacti, and similar desert vegetation. In addition, there are no significant drainage improvements in undeveloped Valley Areas.

4. Suburban Areas have low- to moderate-density developments comprised of detached family homes or light commercial and industrial uses, and often have relatively uniform, gentle slopes with only some watercourses that are either improved or follow paved streets.

5. Light to Moderate Urban Areas usually have multiple residential dwellings, or moderate industrial and light commercial uses. These areas are similar to Suburban Areas, but with most watercourses being either improved or following paved streets.

6. Highly Urbanized Areas are similar to Light to Moderate Urban Areas, but with a large percentage of the area impervious, and virtually all watercourses are either improved or follow paved streets.

7. Commercial Areas are similar to Highly Urbanized area, but less than 15% of the area remains pervious.

8. Shallow Sheetflow Areas and Overland Flow Areas (restricted use) typically have extremely uniform, flat slopes with no natural or constructed channels. Surface flows do not exceed 0.5 feet in depth. Overland flow occurs at the upper reaches of a watershed where the flow is not channelized, within minor watersheds, or over relatively short distances. Along natural surfaces, ground cover may consist of cultivated crops or substantial growth of grass and fairly dense, small shrubs, cacti or similar desert vegetation. Generally, no drainage improvements exist in these areas. *The use of Basin Factors for Shallow Sheetflow Areas is restricted. The user shall obtain approval from the PRCFCD prior to applying the Shallow Sheetflow Basin Factors listed in Table 4.3. to any watershed or portions of a watershed. Furthermore, the user shall provide written and photographic justification for selecting these Basin Factors with any subsequent drainage analysis submitted to the PRCFCD for review or approval.*

Basin Factors shall be selected for future, fully developed conditions, based on the best available information regarding future land use potential. When calculating flood peaks using PC-HYDRO, the user shall describe this future land use, and the published source from which this information or projection was obtained.

2.4.9 Mean Watershed Slope

The calculation of Time of Concentration requires the measurement of hypothetical uniform slope for the longest watercourse within a watershed which would give the same travel time through the watershed as a reach-by-reach calculation. An assumption is made in the derivation of Equation 9, below, that the roughness coefficient and hydraulic radius of the watercourse are the same for all reaches of the watershed; that is, the watershed is homogeneous. Further, according to Manning's equation, the travel time is inversely proportional to the square root of its slope. Thus, the following equation is used in the Pima County Hydrology Procedures to calculate the slope of the longest watercourse within the watershed under investigation (Johnstone and Cross, 1949; Singh, 1996):

$$S_c = \left[\frac{L_c}{I}\right]^2 \qquad \text{\{Equation 8\}}$$

Where:

- S_c is the equivalent or mean watershed slope of the longest watercourse, in ft/ft;
- L_c is the length of the longest watercourse, in feet, measured from the outlet to the watershed divide; and,
- I is defined by Equation (9a or 9b), below.

$$I = \sum_{i=1}^{n}\left[\frac{L_i^{\,3}}{H_i}\right]^{0.5} \qquad \text{\{Equation 9a\}}$$

$$I = \left[\frac{L_1^{\,3}}{H_1}\right]^{0.5} + \left[\frac{L_2^{\,3}}{H_2}\right]^{0.5} + \left[\frac{L_3^{\,3}}{H_3}\right]^{0.5} + \ldots\left[\frac{L_n^{\,3}}{H_n}\right]^{0.5} \qquad \text{\{Equation 9b\}}$$

Where,

- L_i is the incremental length of the longest watercourse, feet, corresponding to its incremental change in height, H_i; and,
- H_i is the incremental change in elevation, feet, corresponding to the incremental length of longest watercourse, L_i.

To apply equations 8 and 9, it is necessary to divide the longest watercourse into increments or segments, where each segment is represented in Equation 9b by a numerical subscript (e.g., 1, 2, 3, etc.).

The number of incremental slope lengths will depend on watershed slope and land use. It is recommended that the user add slope lengths whenever there are significant slope changes along the watercourse, where another flood peak may need to be calculated, or where there are differences in adjoining land use, stream confluences, degrees of channelization, or Basin Factors (n_b). In general, four increments are usually enough for watersheds exhibiting uniform characteristics and slopes. Unless the watershed under investigation has a constant, uniform slope, it is strongly recommended that the longest watercourse be incremented, rather than measured whole from the watershed divide to the outlet, otherwise, the calculated slope may be too large, resulting is an overestimation of the design flood peak.

2.4.10 Iterative Solution for Time of Concentration

Inspection of Equation 1 and Equations 7a and 7b, reveals that both peak discharge (Q_p) and Time of Concentration (T_c), are functions of runoff supply rate, q. Consequently, these two fundamental equations must be solved iteratively, by first assuming a value for Time of Concentration , and using it in Equation 2 to calculate q. Then, applying the calculated value for q to Equation 7a or 7b to find T_c .

In this iterative process, both the initially assumed estimate of T_c and the resulting calculated value of T_c must be found nearly equal. This iterative process is repeated until reaching satisfactory agreement.

Once a reasonable agreement has been reached, then the final value calculated for q can be substituted into Equation 1 of the Pima County Hydrology Procedures in order to calculate the desired flood peak. With the PC-HYDRO program, the iterative solution takes place in the program to a tolerance of less than 0.06 minutes.

2.4.11 Calculating Rainfall Intensity at Time of Concentration

The rainfall intensity, i, at the watershed Time of Concentration is calculated by interpolation using the rainfall Intensity-Duration-Frequency data obtained for the watershed centroid from NOAA Atlas 14.

In theory, if the duration of the selected design storm is longer than the Time of Concentration, then the calculated rainfall intensity, which is the rainfall depth averaged over the storm duration, will be less than that calculated at the Time of Concentration, and consequently, the peak discharge calculated using the PC-HYDRO program will be less than its maximum or optimal value. Conversely, if the chosen storm duration is less than the Time of Concentration, then the watershed is not fully contributing runoff to the outlet, and the calculated discharge will be less than that calculated at the Time of Concentration.

Therefore, the maximum peak discharge is calculated whenever the chosen storm duration is equal to the Time of Concentration, and any storm durations that are either larger than, or less than, the Time of Concentration will result in an underestimation of the maximum peak discharge.

2.4.12 Calculating the 100-Year Peak Discharge

Equation 1 of Pima County Hydrology Procedures is used to calculate the peak discharge for a given return period by substituting values for area-weighted runoff coefficient (C_w), rainfall intensity (i) , and drainage area (A), as determined using the procedures presented in this User Guide.

2.4.13 Calculating Peak Discharges for Lesser Return Intervals

Vegetation, such as grass, that provides roughness in a low flow, may be flattened in a large flow (Phillips et al. 1998). For this reason, Basin Factors (n_b) can vary with flood-recurrence, and Basin Factors selected for 100-year events may be inappropriately large for smaller storm events. Therefore, the Ratio Method was developed to help ensure that flood peaks for small events were not under-predicted (Zeller, personal communication, 2006). For smaller watersheds, both ratios, and direct calculations using smaller return-period rainfall may provide reasonable results. However, for larger watersheds (with a Time of Concentration greater than 30 minutes) the Ratio Method may be preferable (Zeller, personal communication, 2006). Table 5 provides a list of ratios of the smaller, more frequent floods to the 100-year flood peak (PCDOT&FCD, 1979). These ratios are approximate, and were developed by examining published regional regression equations for southern Arizona and elsewhere, available at that time.

Table 5 – Approximate Ratios of Lesser Magnitude Floods to the 100-Year Flood

Watershed Development	2-Year	10-Year	25-Year	50-Year
Rural	0.10	0.35	0.55	0.75
Suburban	0.15	0.40	0.60	0.80
Moderately Urban	0.20	0.45	0.65	0.85
Highly Urban	0.25	0.50	0.70	0.85

In the context of calculating lesser magnitude floods using the ratios in Table 5, the following general watershed descriptions apply.

Rural: Watersheds which are in a natural or undeveloped condition, or where the anticipated future development will be negligible.

Suburban: Watersheds which contain, or are anticipated to contain, an average of two houses per acre, or less, and with drainage improvements being few or nonexistent.

Moderately Urban: Watersheds which contain, or are anticipated to contain, an average of two to four detached houses per acre, or less, and with drainage improvements ranging from minor to extensive.

Highly Urban: Watersheds which contain, or are anticipated to contain, an average of more than four houses per acre (including multiple dwellings, and commercial and industrial developments), and with extensive drainage improvements.

These general watershed descriptions are consistent with development types listed in Table 3.

The application of these ratios is only applicable under "average" watershed conditions within reasonably homogeneous watersheds. If the watershed under investigation is atypical, or nonhomogeneous, then these approximate ratios shall not be applied.

2.5 Pima County Dimensionless Hydrograph

When a design hydrograph is needed, then the procedure given in Section 3.1.3 of the Pima County Stormwater Detention/Retention Manual (PCDOT&FCD, 1987) may be used. It was developed in part on a dimensionless synthetic hydrograph developed by Hickok and others (1959) from observations at 14 semiarid experimental watersheds in southern Arizona and elsewhere. Within PC-Hydro, this synthetic hydrograph procedure takes place in the program.

2.6 Selection and Evolution of the Pima County Hydrology Procedures

The method outlined within this User Guide employs a concept in general use, namely that the peak discharge of a watershed occurs when the hydraulically most remote point of the watershed contributes at the outlet (i.e., the entire drainage area is contributing to the discharge). As a consequence of this fact, one of the most important factors needed for the determination of peak discharge is the Time of Concentration, defined as the time required for water to travel from the hydraulically most remote point in the watershed to the outlet under investigation. A considerable amount of research has gone into the investigation of various formulas used to estimate the Time of Concentration for both gaged and ungaged watersheds. The equation which finally evolved for use within the Pima County Hydrology Procedures is semi-empirical in nature and is utilized because it has been determined that it reproduces, with the most consistent accuracy, measured peak discharges within Pima County, Arizona (PCDOT&FCD, 1977).

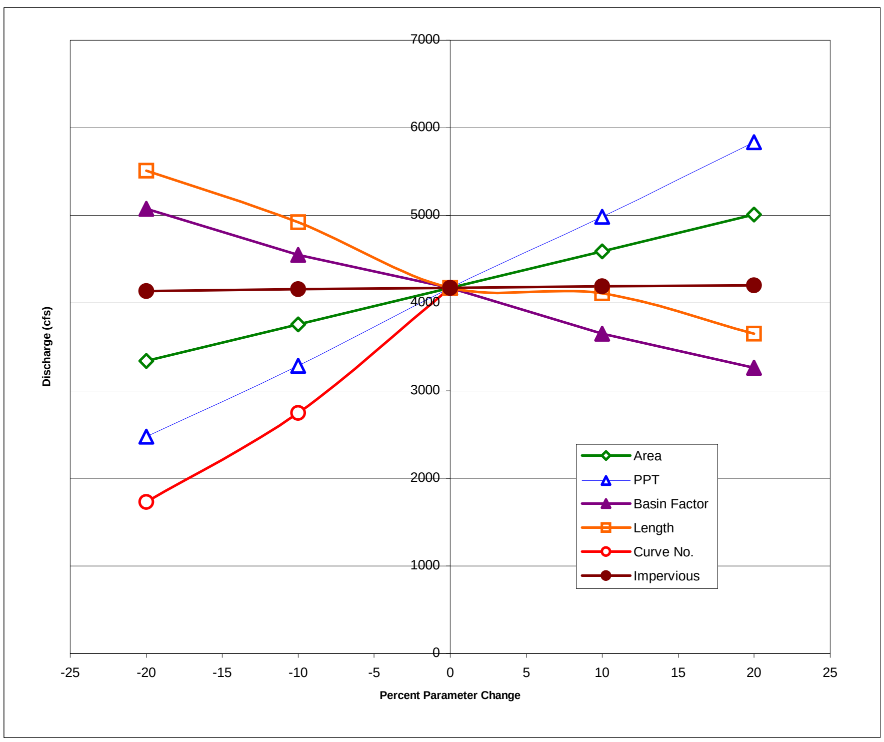
The equation, therefore, differs from most formulas for Time of Concentration by the fact that recognition is given to the effect of rainfall depths (i.e., the hydraulic efficiency of the watershed is influenced by variable depths of flow), as well as the effect of hydraulic roughness upon travel time through a watershed (PCDOT&FCD, 1977).

The calculation of Time of Concentration using Equation 7 is unique to the Pima County Hydrology Procedures. It is believed to be reasonable. For example, a study of the upper and lower Forty-Niner Wash found that the Time of Concentration calculated using Equation 7 was shorter than ten of the twelve common Time of Concentration equations examined (Lantz, 1989).

2.7 Model Sensitivity to Variations in Input

Like most hydrologic models, the flood peaks calculated by PC-HYDRO are comparatively more sensitive to some input parameters than others. A sensitivity analysis was performed on the watershed described in Example 4, Enchanted Hills (Appendix F). On other watersheds, site conditions may dictate which parameters are most important. Figure 4 shows the relative change in the calculated peak discharge for each +/-20% change in each of the input parameters: Area, precipitation, Basin Factor, length of the longest watercourse, base Curve Number, and percent of Impervious Cover.

Figure 4 – Relative change, or sensitivity, of Calculated Peak Discharge for each 10% change in six input parameters



In this scenario, the calculated peak discharge is most sensitive to the selection of base Curve Number. A 10% reduction in base CN results in more than a 20% reduction in peak discharge. Increases in CN were not studied, because PC-HYDRO limits CN values to less than 93, and thus did not allow a 10% increase in the D-type soils found on Enchanted Hills. The model is also highly sensitive to precipitation input, with a 10% change in precipitation resulting in a greater than 10% change in predicted peak discharge. The remaining three parameters, Area, Basin Factor (n_b), and watercourse length (L_c), have a lesser, and nearly equal affect. Because peak discharge is directly proportional to Area, as indicated in Equation 1, a 10% reduction in Area results in a 10% decrease in peak discharge. Changes in Basin Factor (n_b) or watercourse length (L_c) have a nearly proportional impact on predicted peak discharge. However, the changes are inversely-proportional, with decreases in these two inputs producing increases in predicted peak discharge. In this example, Basin Factors varied only 20%. Whereas, Basin Factors have an acceptable range of over 400% in Tables 4.1, 4.2 and 4.3. Consequently, Basin Factors may be one of the most critical parameters. Within the range studied, Impervious Cover (9% +/- 20%) has little effect on calculated peak discharge.

The sensitivity analysis shows that all six of these parameters are relatively important. However, it is important to recognize that the steps taken to identify the base Curve Numbers are the most critical. The model is also highly-sensitive to rainfall, so it is important to find the rainfall node in NOAA 14 that is most-indicative of the conditions of the centroid of the watershed. Likewise, it is important to recognize that changes in Area, Basin Factor (n_b), watercourse length (L_c) may result in a proportional change in predicted peak discharge, with changes in Basin Factor or watercourse length being inversely proportional.

2.8 Capabilities and Limitations

PC-HYDRO can be used to calculate flood peaks, for varying frequencies, from 2-years to 500-years, for both existing and proposed land use and hydrologic conditions. It is a hydrologic model, not a hydraulic model. It is to be used by engineers, hydrologists, and floodplain managers familiar with arid-land hydrology, in the analysis and design of natural and constructed drainage systems located in unincorporated Pima County, Arizona. However, the use of PC-HYDRO has limitations:

1. The contributing drainage areas must be less than or equal to 10 square miles;
2. The Time of Concentration must be less than 180 minutes;
3. The watershed must be relatively homogeneous; and,
4. The watershed must not be controlled by flood-control reservoirs or basins.

The Pima County Hydrology Procedures are subject to the following simplifying assumptions common to small watershed hydrologic models:

- Rainfall is uniformly distributed over the entire watershed;
- Rainfall occurs at a uniform intensity for a duration at least equal to the Time of Concentration;

- Peak rate of runoff is proportional to rainfall intensity or rainfall depth averaged over a time period equal to the Time of Concentration;
- The return period of the runoff event is the same as the return period of the precipitation event; and,
- Channel storage processes or diffusion are negligible.

Furthermore, the application of this method also requires additional assumptions:

1. The original method (ADOT, 1968) used to derive the base CN must be used with PC-HYDRO to derive the base CN, even though newer methods exist.
2. The values used to represent the Basin Factor shall correspond to those listed in Tables 4.1, 4.2 and 4.3, and shall represent future watershed and watercourse conditions, irrespective of whether or not future stormwater detention will be required. If the watersheds are not yet developed to the maximum allowed by the applicable zoning, Basin Factors should be adjusted to represent future conditions.
3. When selecting representative values for impervious cover, the user shall assume existing watershed conditions if stormwater detention will be required as a condition of future development within the entire watershed. Otherwise, the user shall assume future conditions based on allowable Land Use Intensities given in the Pima County Comprehensive Plan, or other reliable sources of information.
4. Regardless of whether or not stormwater detention/retention will be required as a condition of future land development, when selecting values for the Basin Factor the user shall assume future conditions based on allowable Land Use Intensities given in the Pima County Comprehensive Plan, or other reliable sources of information.

PC-HYDRO is a hydrologic model, with no explicit description of channel hydraulics. Therefore, it has limitations in its ability to predict discharge rates when travel times are strongly-dependent on channel hydraulics, or channel storage. In some cases, the user might want to compare the estimated travel-time and travel velocities with a hydraulic model to determine if PC-HYDRO is providing reasonable results.

3.0 PC-HYDRO Input Description

Inputs into PC-HYDRO are generally entered sequentially into a series of Data Input Forms, starting with the name and brief description of the project, then followed by information concerning the watershed characteristics, rainfall intensity and frequency, as well as soil and vegetation data. The user also has the option of calculating flood peaks for each desired return period, or alternatively using ratios of the 100-year peak discharge. The steps taken to input data into PC-HYDRO are presented in the Quick Start Guide found in Appendix C.

3.0.1 Program Organization

PC-HYDRO is organized into eight Data Input Forms, or windows. From them, data can be reviewed, accepted, or modified. These Data Input Forms include a Beginning Window, a Terms and Conditions Window, a Summary Page, a Project Data Form, a Watershed Data Form, a Rainfall Data Form, a Soil/Vegetation Data Form, and a Ratios of Lesser Return Periods Form. Each of these forms are described below.

3.0.2 Toolbar (Website Links and Help)

The Summary Page Form has a Toolbar located at the top of the window from which additional information can be obtained or accessed. The remaining Data Input Forms also have a Toolbar, but they only have one Help button from which information specific to the particular input form is provided, enabling the user to review information regarding the data that are to be entered.

3.1 Data Input Forms

Following is a sequence of steps for inputting data into PC-HYDRO.

3.1.1 Open Program and Agree to Terms and Conditions

Begin PC-HYDRO, and read and agree to the Terms and Conditions of Use. A complete copy of these Terms and Conditions of Use can be found in Appendix A of this User Guide.

3.1.2 Input Summary Page

After agreeing, the first screen to appear provides a summary page with all the input-data fields left blank. *Important: Input data are not entered anywhere on the PC-HYDRO Summary Page.* To save the data entered into PC-HYDRO, press the FILE button found in the tool set at the top of the Summary Page, select the SAVE button, and then Browse and Save in the preferred file.

3.1.3 Project Data Input Form

Browse for and Open an existing PC-HYDRO file by first pressing the FILE button found in the toolset at the top of the Summary Page, and then selecting the OPEN button. Version 5.x of PC-HYDRO will only open existing data sets having a *.pk5 file extensions. Alternatively, for new projects, press the FILE button in the top tool set, and select NEW. Afterwards, enter Project Data, including Client Name, Project Name, Concentration Point (including whether or not the analysis is for existing or future conditions; for example: "CP#30 Existing"), Job Number, Date, and Prepared by, in the appropriate fields given on the Project Data Input Form.

3.1.4 Watershed Data Input Form

The Watershed Data Input Form has spaces for entering Watershed Area, Watershed Type, Length of Longest Watercourse and the Length to the Center of Gravity, representative Slope Breaks and Basin Factors, all of which are described in more detail below. When selecting representative values for impervious cover, the user shall assume existing watershed conditions if stormwater detention will be required as a condition of future development within the entire watershed. Otherwise, the user shall assume future conditions based on allowable Land Use Intensities given in the Pima County Comprehensive Plan, or other reliable sources of information. Regardless of whether or not stormwater detention/retention will be required as a condition of future land development, when selecting values for the Basin Factor the user shall assume future conditions based on allowable Land Use Intensities given in the Pima County Comprehensive Plan, or other reliable sources of information.

3.1.4.1 Measure the Watershed Area (A)

Identify the boundaries of the watershed contributing runoff to the selected point of drainage concentration by tracing the watershed divides identifiable on topographic contours or aerial photographs, PAG digital topographic data, 7.5-minute U.S. Geological Survey topographic quadrangle maps, or scalable aerial photographs. Afterwards, measure the total area within these boundaries, in acres or square miles. Also identify locations where splitflows may occur, and if needed, measure the drainage area while assuming those splitflow conditions that result in the largest watershed for each concentration point. In distributary and shallow sheet flow areas, delineating watershed boundaries using only U.S. Geological Survey topographic quadrangle maps is not accepted without aerial photograph and/or ground verification of drainage basin boundaries.

3.1.4.2 Measure the length of the longest watercourse (L_c).

Identify the longest watercourse, from the concentration point to the upstream-most divide, by tracing this flow path on available contour maps or aerial photographs. Measure the overall distance, in feet. The measurement must extend to the upstream watershed boundary.

3.1.4.3 Measure the length of the longest watercourse to the center of gravity (L_{ca}).

Visually identify the centroid of the watershed. Draw a line through the centroid and perpendicular to the longest watercourse, and from this point, measure the length of the longest watercourse to the downstream concentration point, in feet. If the watershed shape is nearly symmetrical, the distance L_{ca} can be approximated by dividing the distance L_c by 2.

Because the slope calculation averages each segment according to Equation 8, it is not critical whether segments of the channel are entered into the data screen from the bottom up or from the top down. However, for consistency and ease in adding additional concentration points, it is recommended that data be entered with the highest segment at the top, and the outlet at the bottom segment.

3.1.4.4 Measure incremental slope lengths (Li and Hi)

Divide the line used to represent the longest watercourse in Step 3.1.4.2 into discrete increments, and then measure each incremental length (Li) and incremental elevation difference (Hi). The number of incremental slope lengths will depend on watershed slope and land use. Add slope lengths whenever there are significant slope changes along the watercourse, where another flood peak may need to be calculated, or where there are differences in adjoining land use, degrees of channelization, or Basin Factor (n_b). In general, four increments are usually enough for watersheds exhibiting uniform characteristics and slopes.

3.1.4.5 Classify the watershed type

From field investigations and examination of aerial photographs, the general watershed type should be classified according to the land uses. For developed conditions, development densities listed on Table 3 shall be used (e.g., suburban, moderately urban, or high density urban). Values in Table 4 shall be used to select appropriate Basin Factors (n_b) for all watershed conditions.

3.1.4.6 Classify the Basin Factor (nb) for each slope-length segment

From field investigation or aerial photographs, identify the Basin Factor (n_b) that best represents each slope-length segment developed during Step 3.1.4.4. The values to be used should correspond to those listed in Table 4, and represent future watershed and watercourse conditions, irrespective of whether or not future stormwater detention will be required.

3.1.5 Soil/Vegetation Data Input Form

On the Soil/Vegetation Data Input Form, enter Vegetation Cover Density, Vegetative Cover Type, Impervious Cover, and the Percent and Curve Number corresponding to SCS Hydrologic Soil Types B, C, and D. When selecting representative values for vegetation, bare soil and impervious cover types, assume existing watershed conditions when stormwater detention will be required as a condition of future development. Otherwise, assume future conditions based on allowable Land Use Intensities given in the Pima County Comprehensive Plan. Select representative NRCS-SCS Curve Numbers from the Graph on Figure 2, or Appendix D.

3.1.5.1 Estimate the Vegetation Cover Density

A method for estimating percent cover density is described in Appendix E. Three broad ranges of vegetative cover density have been established: Poor (0 % to 20%), Fair (20% to 40%), and Good (40% and above). Typically, 40% is the maximum vegetative density of Desert Brush observed in eastern Pima County. Visual estimates are generally adequate to estimate percent cover. In the absence of reliable information, a value of 20% is recommended.

3.1.5.2 Identify the Vegetation Cover Type

Visually classify the Vegetation Cover Type as Desert Brush, Urban Lawns, Herbaceous, Mountain Brush, Juniper-Grass, or Ponderosa Pine. A description of the vegetative cover types can be found in section 2.4.3.3 of this User Guide.

3.1.5.3 Estimate the Percentage of Impervious Cover

Visually estimate the relative amount of the watershed that is impervious. Either calculate the impervious cover of a representative area within the watershed, or select a minimum, average, or maximum value from Table 3, based on typical types/densities of urban development within the watershed.

3.1.5.4 Select and Enter NRCS-SCS Curve Numbers (CN)

Using the Vegetation Cover Type and Cover Density, select a representative Curve Number for each Hydrologic Soil Group, from type curves given in Figure 2. *Important: The Soil/Vegetation Data Form does not calculate Curve Numbers based on previous input; and any modifications to Vegetation Cover Type will require a corresponding change to Curve Numbers based on the curves in Figure 2.*

3.1.6 Rainfall Data Input Form

On the Rainfall Data Input Form, enter rainfall and flood Return Period, Rainfall Input (entering either Latitude and Longitude coordinates for the watershed centroid, or rainfall intensity/duration values independently obtained from the NOAA Atlas 14, Upper 90% Confidence Limits), and Arial Reduction Factors for watersheds larger than 10 square miles. Values representing Latitude and Longitude can be entered with up to 4 significant figures. Alternative rainfall values must be approved by the Pima County Regional Flood Control District.

3.2 Procedure for Evaluating Nonhomogeneous Watersheds

If runoff characteristics are not evenly-distributed across a watershed, they are said to be 'nonhomogeneous.' An example would be an industrial complex in an otherwise undeveloped watershed. PC-HYDRO calculates a weighted Basin Factor, which results in a weighted runoff to rainfall ratio (C_w) assuming that a single watercourse drains all subasins in the watershed.

The weighting is proportionate to the length of the flow path applicable to each Basin Factor:

$$n_{b\,avg} = \sum_{i=1}^{n} \frac{n_{b\,i} L_i}{L_c}$$ {Equation 10a}

$$n_{b\,avg} = \frac{n_{b1} L_1}{L_c} + \frac{n_{b2} L_2}{L_c} + \frac{n_{b3} L_3}{Lc} + \ldots\ldots \frac{n_{b\,n} L_n}{L_c}$$ {Equation 10b}

Where:

$n_{b\,avg}$ is the average Basin Factor for use in equation 7a or 7b;

n_{bi} is the Basin Factor for flow segment i;

L_i is the incremental length of the longest watercourse, in feet, corresponding to its incremental change in Basin Factor. *(Note: This may or may not correspond to the incremental change in slope described in Equations 9a and 9b)* and;

L_c is the length of the longest watercourse, in feet, measured from the outlet to the watershed divide as previously described in Equation 8.

3.2.1 Highly Impermeable Sub-basins

It is possible for a sub-basin to contribute a higher discharge than the watershed as a whole. An example of this is described in the original hydrology manual (p. 28 to 31 of PCDOT&FCD, 1979) where a 500-acre industrial park near the watershed outlet contributed a higher peak than the remaining 1500-acre desert brush upstream, or the full 2000-acre watershed with weighted input values.

In order to evaluate the possible impact of the industrial park, the 500-acre industrial park was treated as a separate watershed. Because the industrial park was impermeable and had a lower Basin Factor, the Time of Concentration for the industrial park was calculated at 18 minutes for the 100-year event as opposed to 110 minutes for the entire 2000-acre watershed. Even though the industrial park was only a quarter of the watershed area, the much shorter Time of Concentration resulted in a higher discharge from the industrial park (2339 cfs) than from the weighted values in the entire basin (1935 cfs). In effect, the higher rainfall intensity calculated using the shorter Time of Concentration from the industrial park overcame the fact that the industrial park was only a quarter of the entire watershed.

If highly impermeable sub-basins exist on a watershed, users are advised to determine if the highly impermeable area might be the dominant source of the maximum peak discharge emanating from the watershed as a whole.

4.0 PC-HYDRO Output Description

4.1 Calculate the Flood Peak for a Specified Return Period

After entering information into each of the nine Data Entry Forms, as described in the preceding section of this User Guide, press the Calculate button located near the top of the Summary Page. Upon doing this, the peak discharge for the specified return period will be listed in the Runoff Data summary portion of the Summary Page. The rainfall Time of Concentration, Rainfall Intensity, and Runoff Supply Rate will also be listed.

The input data and output summary can be saved to a user-defined file, or sent to the default printer by selecting the desired action from the pull-down menu found after pressing the File button located in the upper left-hand corner of the Summary Page, as seen below in Figure 5.

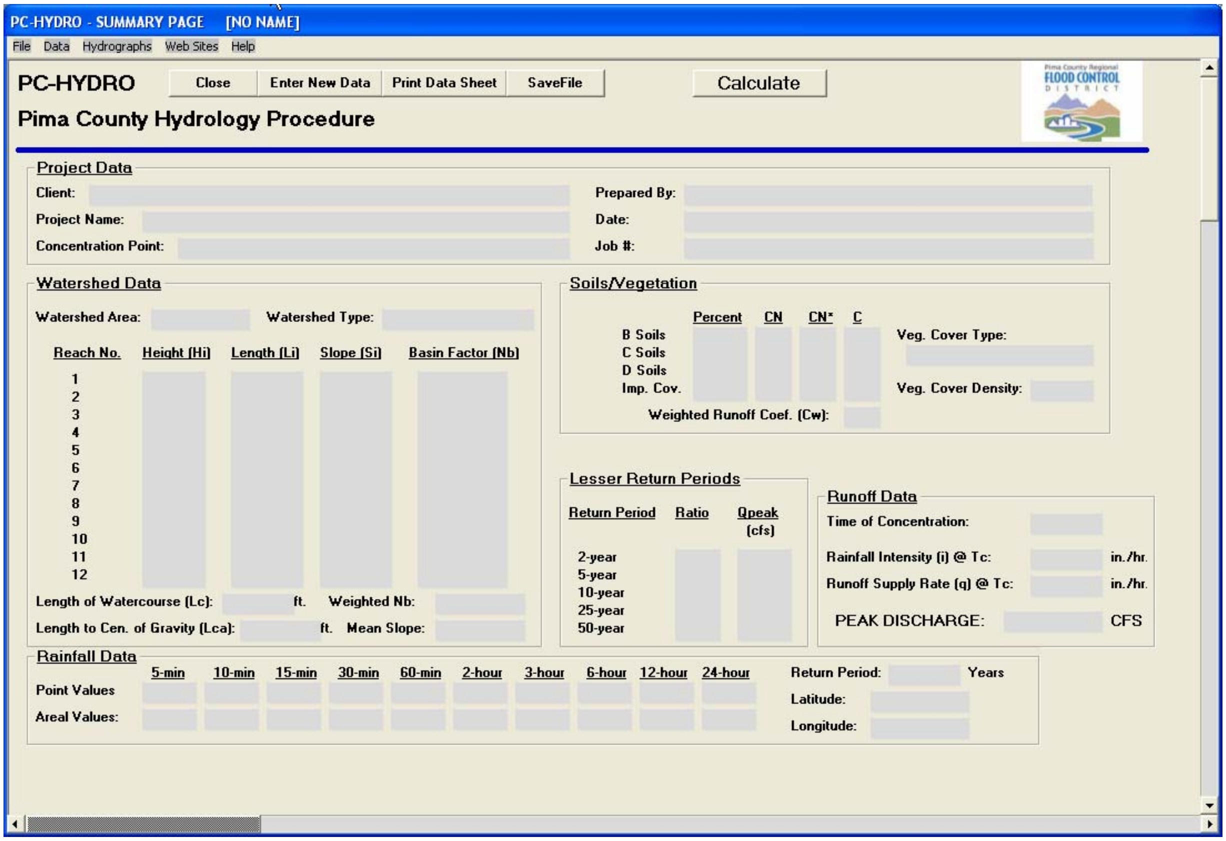


Figure 5 – Typical PC-HYDRO Summary Page

4.2 Calculate Flood Hydrograph

A Pima County Synthetic Hydrograph can be generated, with user-defined time increments, and either sent directly to the Windows Default Printer, or Browsed and Saved as an ASCII Text File at a user-defined location. This hydrograph is based on the dimensionless hydrograph given in Section 3.1.2 of the Stormwater Detention/Retention Manual (PCDOT&FCD, 1987; Hickok and others, 1959).

4.3 Evaluation of Results

The flood peak, Time of Concentration, and Weighted Runoff Coefficient must be checked by the user once these values have been calculated by PC-HYDRO. Make sure these results are reasonable for the purpose at hand. It is also recommended that other methods be used as an independent check.

The input data should also be checked once the calculations have been made. Site conditions will dictate which parameters are most important. However, particular attention should be given to base Curve Number, impervious cover, precipitation amounts, Basin Factors, watershed area, and length of the longest watercourse.

4.4 Examples

Appendix F of this User Guide provides six examples of how to apply PC-HYDRO to different watershed conditions typically found in unincorporated Pima County. Where observed data exist, the predicted discharge from PC-HYDRO is compared with those observations. These examples include:

> ***Example 1 – Santa Rita Experimental Watershed #4:*** Santa Rita Experimental Watershed #4 is one of eight experimental watersheds located in south-central Pima County at the base of the Santa Rita Mountains on the University of Arizona's Santa Rita Experimental Range. Watershed #4 is 4.9 acres and has a recording rain gage and a Replogle flume that can measure discharges up to 50 cfs (Kidwell and others, 2001). The watershed is maintained by the USDA-ARS Southwest Watershed Research Center, and is located in the shrub-dominated lower portion of the experimental range. Rainfall and runoff records for this experimental watershed have been maintained since 1975. There is only one Vegetation Type within this watershed, and it can be characterized as Desert Brush with a 30% average cover density

Example 2 – Paseo Del Rio Subdivision: Example #2 examines a 5-acre portion of an existing moderate to high-density residential subdivision located along River Road, near La Canada Drive. This subdivision was constructed in 2005, and the roadways and channels are believed to be able to convey the 100-year design floods. There is only one Vegetation Type within this watershed, and it can be characterized as Urban Lawn, with average cover density.

Example 3 – Santa Rita Retail Shopping Center: Example #3 examines a 3-acre portion of a proposed commercial development located near Sahuarita Road and Houghton Road. The slope of the longest watercourse is a moderate 1.5%. The Mannings N-value for the water-carrying parking areas was estimated to be 0.015. There is only one Vegetation Type within this watershed, and it can be characterized as Desert Brush, with poor cover density. The proposed impervious cover is estimated to be 90%.

Example 4 – Enchanted Hills Wash at Mission Rd.: This wash was included in the original Pima County Hydrology Manual as Example 6. The Enchanted Hills Wash is a Rural Foothills and Undeveloped Mountain watershed with the upper 60% of the watershed located inside the Tucson Mountain County Park. Areas outside the park are within incorporated City of Tucson. Additionally, the mouth or concentration point of this 3.1 square mile watershed is located at the former USGS stream gage # 09482480, which was in service for the 17 year period between 1965 and 1981. This wash is also known as Big Wash (not to be confused with the Big Wash in Oro Valley).

Example 5 – High School Wash at Vine Avenue: This wash was included in the original Pima County Hydrology Manual as Example 7. High School Wash can be classified as Shallow Sheetflow (Paved) because it is fully developed with an estimated urban density of 3.1 residences per acre, and the existing unimproved drainageways do not have the capacity to carry the 100-year peak discharge. The dominant cover type is Urban Lawn. This watershed is located within incorporated City of Tucson. Additionally, the mouth or concentration point of this 0.9 square mile watershed is located at the former USGS stream gage # 09483010, which was in service for the 16 year period between 1968 and 1983.

Example 6 - Hot Shot Wash: Hot Shot Wash is a 282 acre watershed south of Ajo, AZ. Data were collected from 1966 to 1981 by the USGS (USGS # 09520110). Hot Shot Wash drains a mountainous area to the west. The slope of the longest watercourse is extremely steep at the top (18%) grading to < 1% in the lower half of the watershed along the valley floor. Vegetation is Desert Brush. The main channel itself is mapped as Xeroriparian C and tends to be brushy.

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