San Diego County Hydrology Manual

Prepared by the County of San Diego
Department of Public Works
Flood Control Section
June 2003

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ACKNOWLEDGEMENTS

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Original Manual

(Published in October 1973)

The manual was based on analysis of rain and stream flow records collected in San Diego and information gathered from the National Resources Conservation Service, the National Weather Service, and the U.S. Army Corps of Engineers.

Current Manual

The current manual was developed by a committee under the direction of Commissioner Mike Sholders. Members of the committee and their affiliation are listed below:

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The objective of this update was to retain as much criteria as possible from the original manual—so that established flood flows would not change unnecessarily—while needed improvements to criteria were included.

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

A	area
A_c	cross sectional area
A_s	soil loss in tons
ALERT	Automatic Local Evaluation in Real Time
ARS	Agricultural Research Service
b	bottom width
BMP	best management practice
C	runoff coefficient
C-factor	cropping management factor
CEQA	California Environmental Quality Act
cfs	cubic feet per second
CN	curve number
CN_2	curve number adjusted to PZN = 2.0
CN_3	curve number adjusted to PZN = 3.0
Corps	United States Army Corps of Engineers
D	duration
d	normal depth
DPWFCS	Department of Public Works Flood Control Section
DU/A	dwelling units per acre
FAA	Federal Aviation Agency
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Studies
fps	feet per second
ft	feet
ft^2	square feet
ft^3	cubic feet
H	head
H_{avg}	(HB + HE) / 2
HB	head at beginning
HE	head at end

HEC	Hydrologic Engineering Center
hr	hour
I	rainfall intensity
I_a	Initial Abstraction
IECA	International Erosion Control Association
in	inches
I_N	actual rainfall intensity at rainfall block N in inches per hour
I_{NTc}	average rainfall intensity for a duration equal to NT_c in inches per hour
$I_{T(N)}$	average rainfall intensity for a duration equal to $T_{T(N)}$ in inches per hour
L	watershed length
lb	pound
L_c	length to centroid
mi	mile
mi^2	square mile
MRM	Modified Rational Method
MSCP	Multiple Species Conservation Plan
N	an integer
$\bar{n}$	basin factor
n	number of hydrograph ordinates
NEH	National Engineering Handbook
NFIP	National Flood Insurance Program
NRCS	National Resources Conservation Service
NWS	National Weather Service
ODP	Office of Disaster Preparedness
P	Total rainfall depth for a duration
P_6	precipitation over 6-hour period
P_{24}	precipitation over a 24-hour period
P_N	precipitation amount for the block in inches
$P_{T(N)}$	total amount of precipitation for any given block (N)
PZN	Precipitation Zone Number
Q	discharge flow rate

Q_a	accumulated direct runoff in inches (over basin area)
Q_{AVG}	average flowrate originating from the entire basin
Q_t	accumulated volume of water at time t
q_i	discharge in cfs at the end of time interval i
q_{avg}	average flowrate in the gutter
q_p	interval peak discharge flow rate
Q_p	peak discharge flow rate
RM	Rational Method
S	potential maximum soil retention
s	slope
s_{AVG}	average slope
SCS	Soil Conservation Service
SUSMP	Standard Urban Stormwater Mitigation Plan
T_b	time of base
T_c	time of concentration (minutes)
T_i	initial time of concentration
T_l	lag time
T_p	time to peak
T_t	travel time
$T_{T(N)}$	NT_c in minutes (N is an integer representing the given block number of precipitation)
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
V	velocity
VOL	volume of runoff
Z	slope ratio
ΔE	change in elevation
ΔP	change in precipitation
ΔS	change in storage
ΔT	change in time
ΣCA	weighted runoff coefficient

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GLOSSARY

Accumulated rainfall - (aka Cumulative rainfall, Potential maximum runoff) The total volume of rain that falls on a particular area over a specified time.

Accumulated direct runoff - (aka Excess rainfall) That volume of the rain of a given storm that falls at intensities exceeding the infiltration capacity of the watershed.

Agency - Governing body tasked with reviewing projects for conformance with requirements.

Annual grass - Land on which the principal vegetation consists of annual grasses and weeds such as annual bromes, wild barley, soft chess, ryegrass, and filaree.

Barren - Areas with 15% or less of the ground surface covered by plants or litter. It includes rockland, eroded land, and shaped or graded land. Barren land does not include fallow land.

Base flow - The part of the discharge that enters a stream channel from groundwater.

Basin area - (aka Drainage area, Watershed) The area of land that contributes water to the stream.

Broadleaf chaparral - Areas on which the principal vegetation consists of evergreen shrubs with broad, hard, stiff leaves such as manzanita, ceanothus, and scrub oak. The brush cover is usually dense or moderately dense.

Close-seeded legumes or rotated pasture - Areas of alfalfa, sweetclover, timothy, etc. (and combinations) either planted in close rows or broadcast. This cover may be allowed to remain for more than a year so that year-round protection is given to the soil. The land treatments used with row crops are also used with cover, except for row treatments if the seed is broadcast.

Contoured fields - Fields farmed as nearly as possible on the contour. Contouring affects runoff and infiltration due to the surface storage provided by the furrows because the storage prolongs the time during which infiltration can take place. The magnitude of storage depends not only on the dimensions of the furrows but also on the land slope, crop, and manner of planting and cultivation. Planting small grains or legumes on the contour makes small furrows that disappear because of climatic action during the growing season. The contour furrows used with row crops are either large when the crop is planted and made smaller by cultivation or small after planted and made smaller by cultivation, depending on the type of farming.

Contractor - Person(s) or company, being a licensed contractor with the State of California, responsible for constructing the project in conformance with the plans and applicable construction regulations.

County - Refers to the County of San Diego.

Cumulative rainfall - see Accumulated rainfall.

Deposition - An increase in the channel bed elevation due to collected sediment.

Desiltation basin - Consists of a depression and piping system that is designed to contain and slow the flow of stormwater to a sufficient velocity enabling sediments to fall out of suspension so they are not transported downstream.

Dimensionless unit hydrograph - A hydrograph plotted in dimensionless units with respect to flow and time.

Direct runoff - (aka Excess rainfall) see Accumulated direct runoff.

Discharge volume - Total volume under the outflow hydrograph.

Drainage area - (aka Watershed, Basin area)

Dryland pasture - Equivalent to annual grass.

Engineer - Registered Engineer who is designated as the Engineer-of-Work for the project being evaluated.

Erosion - Process by which soil particles are displaced and moved from one location to another by the actions of wind or water.

Erosion control plans - Detailed plans prepared by the Engineer that depict the schematic location of erosion control devices to be implemented with a project. These are typically attached to grading plans being reviewed by an Agency.

Evergreen - Land planted to evergreen trees including citrus and avocado orchards and coniferous plantings. The effectiveness of this kind of land use is in part determined by the tree, the litter, and the ground cover. In these groves, the ground cover may be legumes alone or annual or perennial grasses with or without legumes. The ground cover may be entirely litter if the tree canopy is sufficiently dense to produce a substantial quantity of fallen leaves or needles (see Table 4-5). As with deciduous orchards, management practices affect the runoff potential of evergreen orchards. Tables 4-3 and 4-4 will help identify the appropriate hydrologic condition for different areas of the plantings.

Excess rainfall - (aka Accumulated direct runoff)

Fallow - Fallow land is land plowed but not yet seeded or tilled. It is more effective than barren land in reducing storm runoff.

Frequency of peak discharges - The same as that of the rainfall intensity for the given time of concentration.

Good rotations - Generally contain alfalfa or other close-seeded legume or grass to improve tilth and increase infiltration. Their hydrologic effects may carry over into succeeding years after the crop is removed, though normally the effects are minor after the second year.

Hydrograph - A graph showing, for a given point on a stream, the discharge flow rate of water with respect to time.

Hyetograph - A graph showing, for a given watershed, increments of average rainfall during successive units of time during a storm.

Initial time of concentration - Time required for runoff to travel across the initial subarea from the most remote point to the point of interest.

Inlet time - Time required for the stormwater to flow to the first inlet in the system.

Irrigated pasture - Irrigated land planted to perennial grasses and legumes for production of forage, and which is cultivated only to establish or renew the stand of plants. For hydrologic purposes, dryland pasture is considered as annual grass.

Junction - (aka Confluence)

Lag - Time to 50% of total discharge volume at point of interest.

Length of overland flow - Length between the farthest point in the subarea number 1 to the design point.

Meadow - Land areas with seasonally high water table, locally called cienegas. Principal vegetation consists of sod-forming grasses interspersed with other plants. The grass is continuously grown, protected from grazing, and generally mowed for hay.

Narrowleaf chaparral - Land on which the principal vegetation consists of diffusely branched evergreen shrubs with fine needle-like leaves such as chamise and redshank. The shrubs are usually widely spaced and low in growth. If the narrowleaf chaparral shrubs are dense and high, the land should be included with broadleaf chaparral cover.

Natural hydrograph - Hydrograph created from data collected with stream gauges or other in-field methods.

Open brush - Principal vegetation consists of soft wood shrubs, usually grayish in color. Examples include California buckwheat, California sagebrush, black sage, white sage, and purple sage. It also includes vegetation on desert facing slopes where broadleaf chaparral predominates in an open shrub cover.

Orchards, deciduous - Land planted to such deciduous trees as apples, apricots, pears, walnuts, and almonds. The ground cover during the rainy season alters the hydrologic response to storm rainfall. Ground cover may be annual grass or perennial grass with or without legumes. Occasionally legumes are used alone. Use CN values that apply to the land use or the kind and condition of cover during storm periods; for example, annual grass CN values for annual grass or grass legume ground cover. If orchards are kept bare by disking or through the use of herbicides, use fallow curve numbers. Under typical management practices, ground cover in orchards varies in vegetative density and, consequently, in effectiveness in reducing runoff. Only orchards with more than 75% of the ground surface protected by cover should be considered in good hydrologic condition. See Tables 4-4 and 4-5.

Overland flow - Surface runoff that occurs in the form of sheet flow on the land surface without concentrating in clearly defined channels.

Peak discharge - (aka Peak runoff) The maximum instantaneous rate of discharge at a given point or from a given area, during a specified period.

Peak runoff - (aka Peak discharge)

Perennial grass - Areas on which the principal vegetation consists of perennial grass, either native or introduced, and which grows under normal dryland conditions. Examples are Stipa or needle grass, harding grass, and wheat grass. It does not include irrigated and meadow grasses.

Point of interest - (aka Design point, Collection point, Concentration point) Point at which Q_p is calculated.

Poor rotations - Generally one-crop land uses such as continuous corn (maize) or continuous wheat or combinations of row crops, small grains, and fallow.

Potential maximum runoff - see Accumulated rainfall.

Project - Proposed development area being analyzed by the Engineer for erosion potential.

Rainfall - (aka Precipitation) Precipitation in the form of water.

Rainfall distribution - The manner in which depth of rainfall varies in space and time.

Rainfall intensity - Average rainfall in inches/hour for a duration equal to the time of concentration for a selected storm frequency.

Rotations - Planned sequences of crops, with the purpose of maintaining soil fertility or reducing erosion or providing an annual supply of a particular crop. Hydrologically, rotations range from “poor” to “good” in proportion to the amount of dense vegetation in the rotation, and they are evaluated in terms of hydrologic effects.

Row crop - Any field crop (maize, sorghum, soybeans, sugar beets, tomatoes, tulips) planted in rows far enough apart so that most of the soil surface is exposed to rainfall impact throughout the growing season. At planting time, it is equivalent to fallow and may be so again after harvest. In most evaluations, average seasonal condition is assumed, but special conditions can be evaluated as shown in Chapter 10, NEH-4 (U.S. Department of Commerce 1985). Row crops are planted either in straight rows or on the contour, and they are in either a poor or good rotation.

Runoff coefficient - The fraction of the rainfall that runs off of the surface.

Runoff hydrograph - The hydrograph constituted by the surface runoff.

Runoff volume - The total quantity or volume of runoff during a specified time.

Scour - Effect that moving water will have on soil, depending on velocity/momentum of water, soil particle size, and soil cohesion.

Sediment - Eroded material suspended in wind or water.

Sedimentation - Deposition of eroded material in any one place.

Small grain - Areas of wheat, oats, barley, flax, etc. are planted in rows close enough that the soil surface is not exposed except during planting and shortly thereafter. Land treatment is the same as used with row crops.

Storm frequency - (aka Design frequency) Frequency is the reciprocal of return period. A frequency of $1/T$, or one in T years, corresponds to a return period of T years. A 25-year storm is one of a magnitude that occurs on average every 25 years.

Straight-row fields - Fields farmed in straight rows either up and down the hill or across the slope. Where land slopes are less than about 2%, farming across the slope in straight rows is equivalent to contouring.

Subarea - (aka Subbasin, Tributary area) The total area, projected upon a horizontal plane, of a drainage basin bounded by the basin perimeter and contributing overland flow to the stream.

Synthetic hydrograph - A hydrograph derived following an established formula, without the need for rainfall runoff data analysis.

Time of concentration - (aka Travel Time, Concentrated flow travel time, Time to peak) The time required for water to flow from the most remote point of the subbasin to the point of interest.

Time to peak - The time from the beginning of runoff (on the rising side of the hydrograph) to the peak flow.

Travel time - (aka Transit time) Time required for stormwater to flow in a storm drain from the initial subarea to the point of interest.

Triangular hydrograph - A triangular hydrograph having the same volume as the curvilinear hydrograph.

Triangular unit hydrograph - A triangular hydrograph having the same volume as the curvilinear unit hydrograph.

Tributary - see Subarea.

Turf - Golf courses, parks, cemeteries, and similar lands where the predominant cover is irrigated, mowed, close-grown turf grasses. Parks in which trees are dense may be classified as woodland.

Unit hydrograph - The direct runoff hydrograph resulting from a rainfall event that has a specific temporal and spatial distribution and that lasts for a specific duration of time (thus there could be a 5-, 10-, 15-minute, etc., unit hydrograph for the same drainage area). The ordinates of the unit hydrograph are such that the volume of direct runoff represented by the area under the hydrograph is equal to 1 inch of runoff from the drainage area.

Vineyards - As with orchards, ground cover and land condition must be considered in estimating CN numbers. Use CN number which applies to the land use or the kind and condition of cover during storm periods: for example, use annual grass CN number for land with this ground cover. CN numbers for “disked” and “annual grass” cover crops are two examples tabulated. As with orchards, the quality of the cover must also be considered. See Tables 4-3, 4-4, and 4-5 for appropriate hydrologic conditions.

Watercourse distance - Length the water travels.

Watershed - (aka Basin, Drainage area)

Woodland-grass - Areas with an open cover of broadleaf or coniferous trees, usually live oak and pines, with the intervening ground space occupied by annual grasses or weeds. The trees may occur single or in small clumps. Canopy density, the amount of ground surface shaded at high noon, is from 20 to 50%.

Woods (woodland) - Areas on which coniferous or broadleaf trees predominate. The crown or canopy density is at least 50%. Open areas may have a cover of annual or perennial grasses or of brush. Herbaceous plant cover under the trees is usually sparse because of leaf or needle litter accumulation.

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SECTION 1
INTRODUCTION

1.1 PURPOSE

The purpose of this manual is to provide an uniform procedure for flood and stormwater analysis within San Diego County. It provides a guide for policies and procedures based upon the science and data available to attain reasonable standardization of hydrology studies throughout the county, but it does not set policy. Please note that each city has jurisdiction over projects within its area and may have policies and procedures differing from those in this manual.

Flood management hydrology deals with estimating flow peaks, volumes, and time distributions of storm runoff. The prediction of these characteristics is fundamental to the design of stormwater management facilities. Errors in the estimates may result in a stormwater management facility that is either undersized and fails to provide public safety and flood protection or oversized and costs more than necessary. On the other hand, the timing, distribution, and intensity of rainfall is a natural process subject to considerable variability. The science of hydrology attempts to make predictions based upon historical rainfall data and an understanding of the relationship between precipitation and runoff.

1.2 BACKGROUND

In the hydrologic analysis for a stormwater management facility, it must be recognized that there are many variable factors that contribute to discharge or runoff. Some of the factors that need to be recognized and considered on an individual site-by-site basis include the following:

- rainfall amount and storm distribution
- drainage area size, shape, and orientation
- ground cover and soil type
- slopes of terrain and stream(s)

- precipitation zone number condition (an index of watershed wetness from antecedent rains)
- storage potential (e.g., overbank, ponds, wetlands, reservoirs, channel)
- watershed development potential
- characteristics of the local drainage system

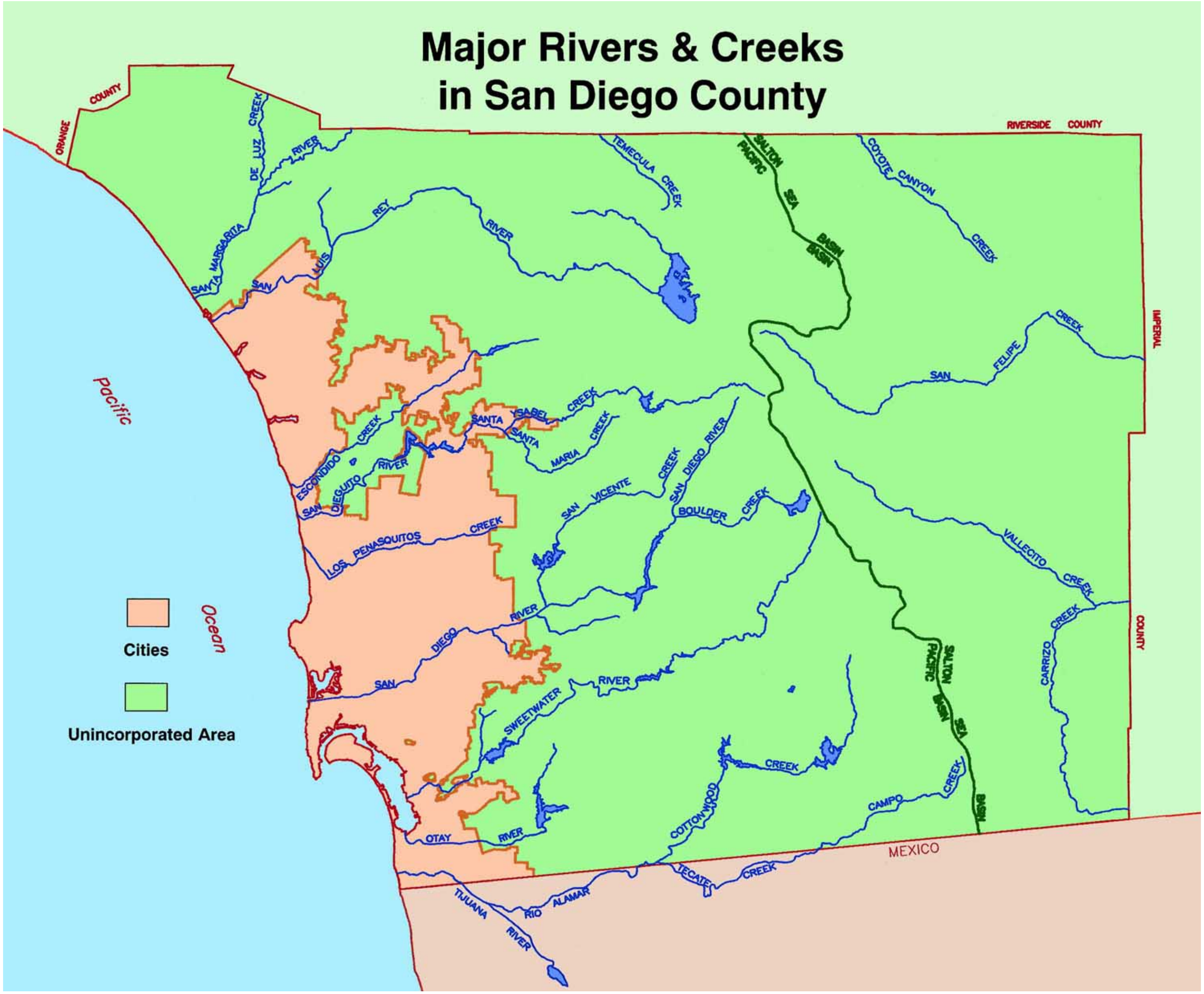
Thus, it is important to select a hydrologic procedure that reflects the actual physical situation encountered in the drainage area being considered. If local stream gauge data are available, these data can be used to develop peak discharges and hydrographs. The user is referred to standard hydrology textbooks for statistical procedures that can be used to estimate design flood events from stream gauge data.

The criteria in this manual are based on a substantial review of many methods used in the United States. The procedures deemed most reliable have been incorporated herein and have been correlated with recorded hydrologic data and analysis of rainfall and runoff events that have occurred within the county. San Diego County is located between MCB Camp Pendleton and Orange and Riverside Counties on the north, the United States/Mexico international border on the south, Imperial County on the east, and the Pacific Ocean on the west. San Diego County encompasses approximately 4,260 square miles and includes a variety of topography, soil types, land uses, and climate, which affects rainfall and storm events. The National Resources Conservation Service (NRCS) has mapped San Diego County, and much of this manual has been based on the NRCS data. Rainfall maps prepared by the National Weather Service (NWS), determined to be accurate for the purpose of this manual, have also been used.

1.2.1 Floods and Flood Control in San Diego County

1.2.1.1 Flood History

San Diego is an area of great climatic variation. The map of San Diego County, Figure 1-1, shows the major rivers and the divide that separates the western and eastern watersheds. This divide follows the mountain ridgeline with elevations that vary from



Major Rivers and Creeks in San Diego County

FIGURE 1-1

Figure 1-1, page 2 of 2 color
"Major Rivers and Creeks in San Diego County"

3,000 to 5,000 feet above sea level. Precipitation that falls east of the divide flows to the Salton Sea Basin, while runoff from precipitation west of the divide flows down the western slope to the Pacific Ocean. Most storms come from the Pacific Ocean toward the mountain ridge. The higher altitude and lower temperature cause the moisture to condense and form rain as it is forced up and over the divide. The effect of this condensation is demonstrated in Figure 1-2. The north/south lines of equal average annual precipitation vary from west to east. The coast receives an average 10 inches in a year, the mountains over 30 inches, and the eastern valley floor about 3 inches.

The Department of Public Works Flood Control Section (DPWFCS) data collection and analysis unit has documented the character of the major storms. Widespread flooding on the western slope is caused by large weather systems that are generated in the Pacific Ocean. However, the most severe local floods, especially in urban areas, are caused by localized, intense thunder storms. Thunder storms, usually in late summer and fall, are also the major source of flood events on the eastern desert slopes. Tropical storms, such as Doreen (1977) and Kathleen (1976) that come from the Tropical Pacific, result in flood flows over relatively large areas in the eastern slope desert type climate.

In addition to spatial variation, climate varies with time. There are years with much less and years with much more than the typical annual rainfall. The 1916 flood resulted from a 2-week period during which the area received about 20% more precipitation than the total average precipitation of the area for a whole year. This resulted in the largest flood of that century. Figure 1-3 shows some of the 1916 flood devastation. At the end of that 2-week flood period, every bridge over every river and creek between San Diego and Orange County in the area was destroyed and the only way to Los Angeles was by boat.

Both the 1980 and 1983 rain seasons were about 80% above average (Figure 1-2). More flood damage occurred in 1980 because the major storms occurred in February after the reservoirs were full from rain in January and the previous fall.

1.2.1.2 Flood Damage Prevention Structures and Programs

Flood Management

The first strategy for avoiding flood danger to life and property consists of identifying the area that would be inundated by a large flood (100-year frequency) and then regulating or restricting development. The regulations require building structures outside of the floodway and protect structures in the floodplain. This has been the primary flood control program in San Diego County since the 1960s. The procedure consists of developing floodplain or alluvial fan maps that identify flood hazard areas (Federal Emergency Management Agency [FEMA] and County Regulated). Figure 1-4 shows the rivers and creeks that have floodplain maps. The areas with alluvial fan maps (Borrego area) are also shown.

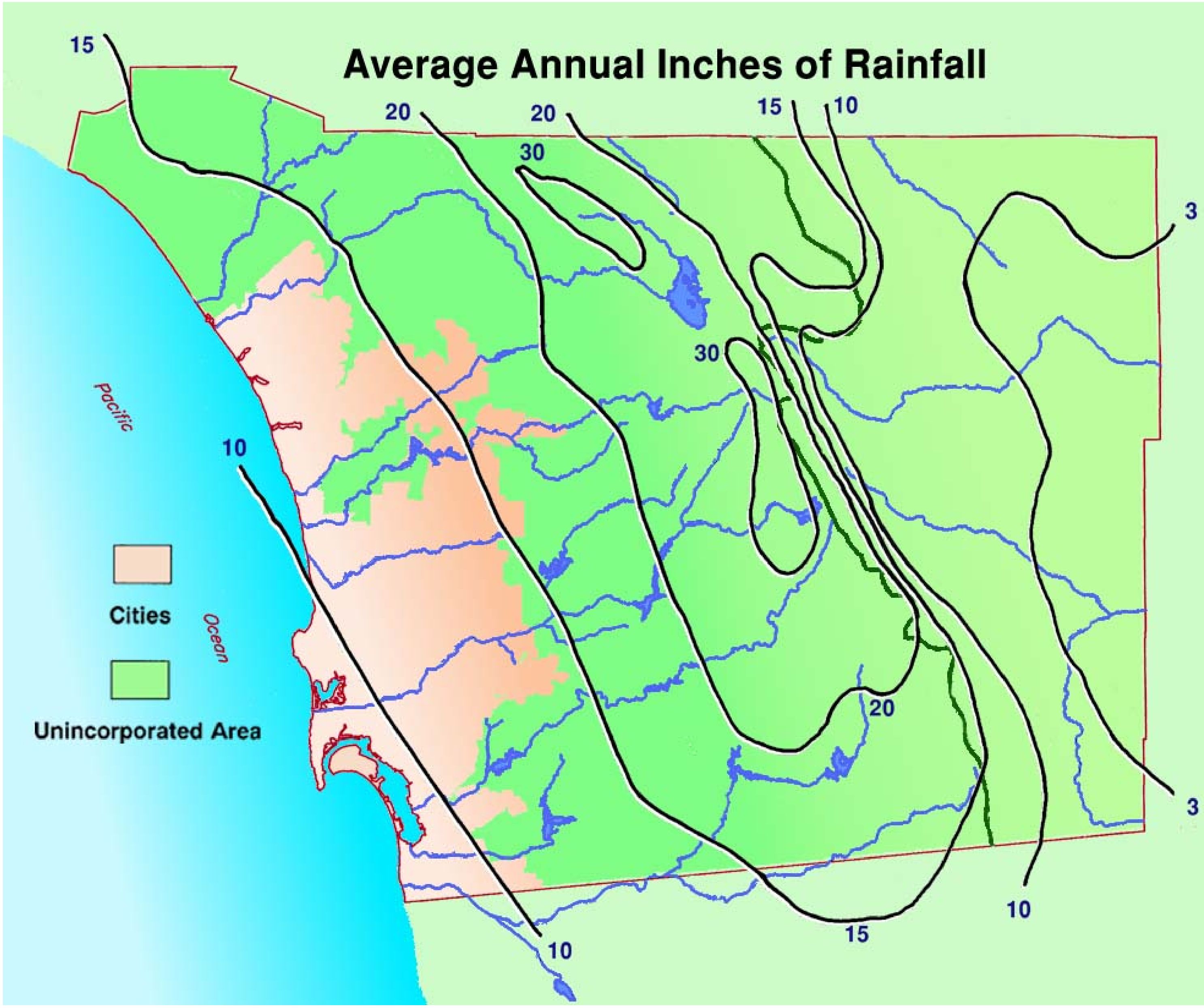
County floodplain maps are based on flood flows developed with criteria included in this manual. Flood areas delineated on maps are compared with subsequent historic floods in the same areas. The flood designations correlate well with historic events and data.

Construction of Flood Control Facilities

A second approach is used to protect people who have already built in a flood-prone area. In this situation, a flood control structure is constructed. Some of the major facilities are identified below (as of 1998):

- Los Coches Creek Channel
- Spring Valley Creek Channels
- Sweetwater Levee System
- Telegraph Canyon Channel
- Escondido Creek Channel
- First San Diego Improvement Project
- San Luis Rey Levee System

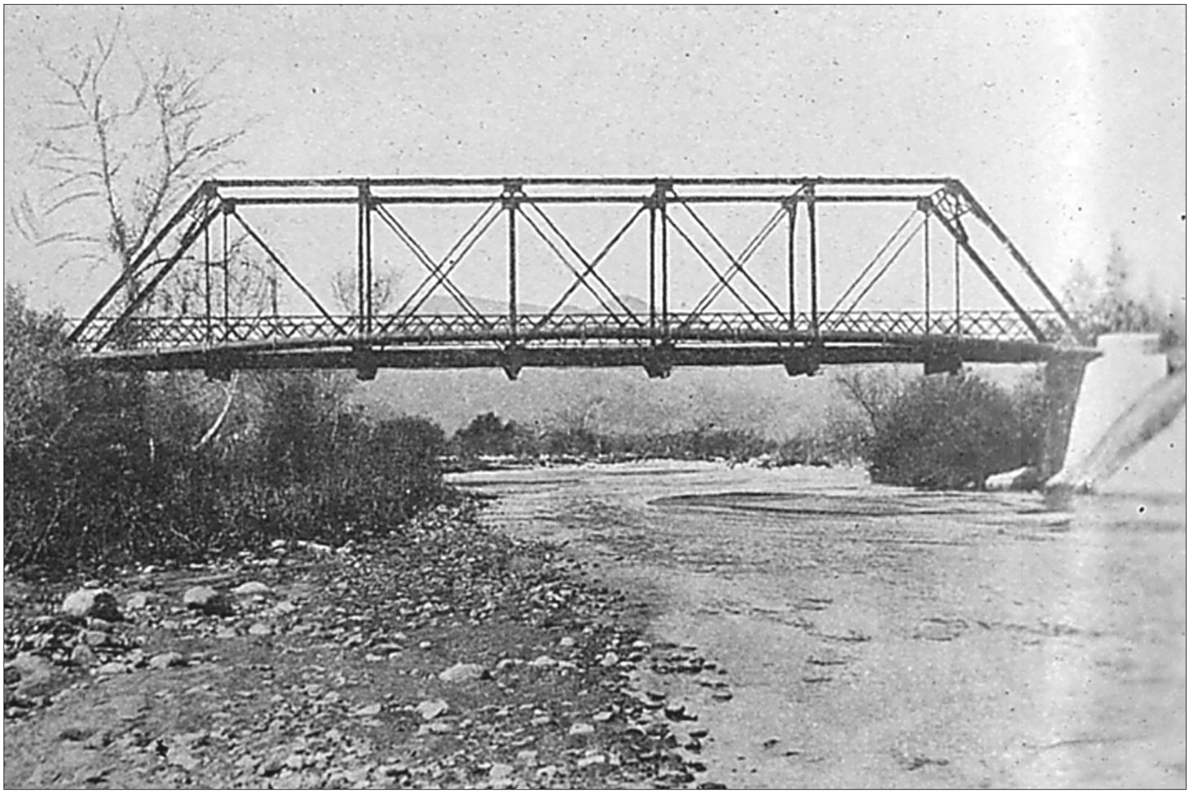
A map of western San Diego County showing the constructed flood control facilities and major reservoirs is given in Figure 1-5.



Average Annual Inches of Rainfall in San Diego
(not to be used for design calculations)

FIGURE
1-2

Figure 1-2, page 2 of 2 color
"Average Annual Inches of Rainfall in San Diego"



Highway Bridge across San Luis Rey River at Pala before the Flood of January 1916

Wreck of Highway Bridge across San Luis Rey River at Pala after the Flood of January 1916

Devastation Caused by the 1916 Flood

FIGURE

1-3

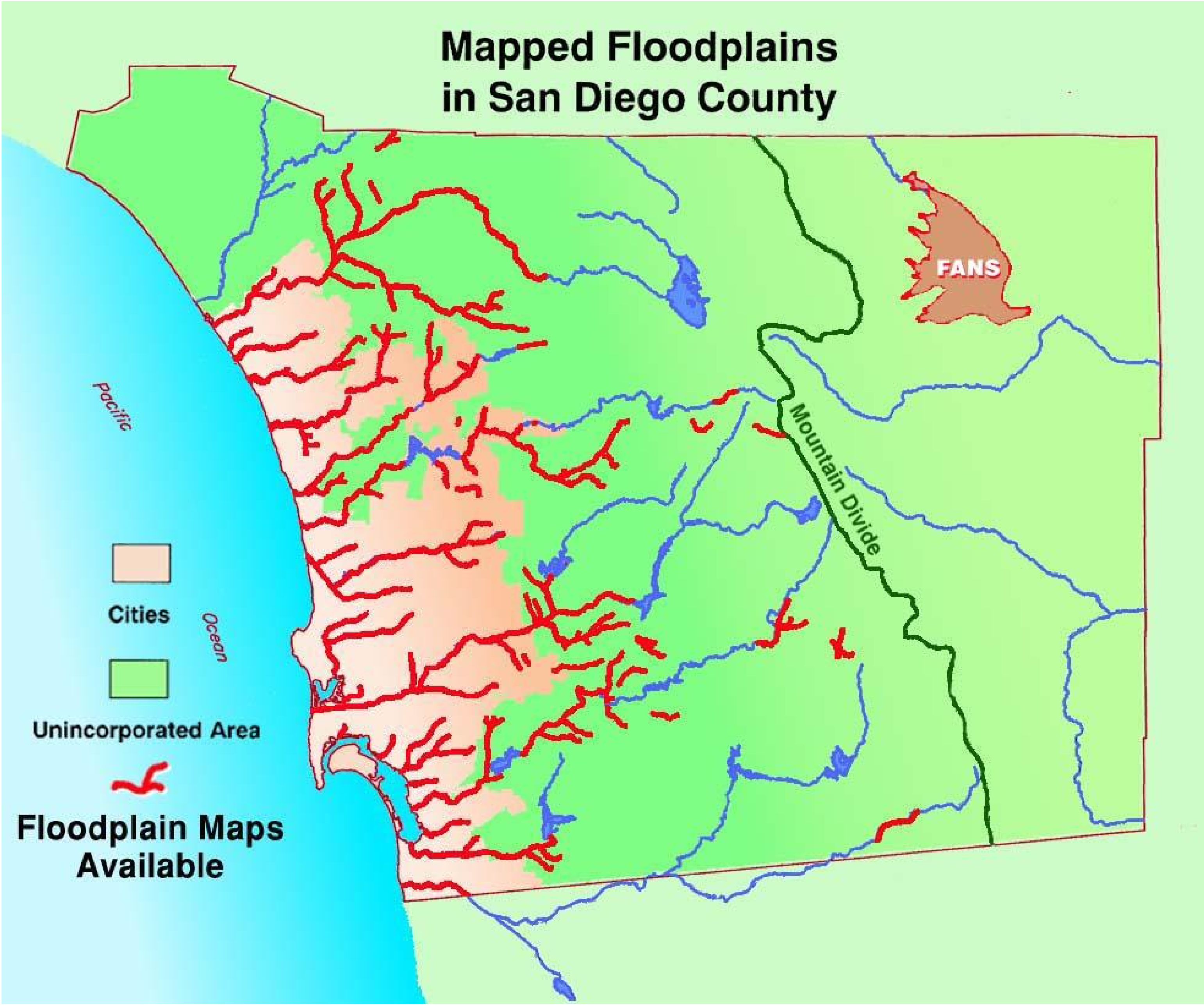
The approximate numbers of miles of rivers and creeks for which the two methods of flood protection have been applied are listed below:

	Unincorporated Areas (miles)	City Areas (miles)
1. Floodplain Mapping	250	120
2. Alluvial Fan Mapping	40	N/A
3. Natural bottom, levees	0	14
4. Concrete channels	14	22

The above table shows that San Diego County (unincorporated area) has focused on flood mapping and management as opposed to construction of flood control facilities to control the damage from flooding. The cost of flood mapping is about $10,000 per mile (2001 dollars) while construction of major flood control facilities varies from $1,000,000 to $20,000,000 per mile. Mitigation for environmental conditions and cost for lifetime maintenance are added expenses.

Maintenance

Maintenance of stormwater management facilities, whether publicly or privately maintained, is of utmost importance in sustaining the aesthetic value and long-term effectiveness of the facility. The level of maintenance needed shall be considered from the time of project planning through the design and permitting process. Where a detention facility is used for open space recreation, the maintenance required may be part of existing programs. If the facility is to be a single-purpose stormwater control project, a funding vehicle shall be established at the project outset to ensure proper maintenance. The facility shall be planned to permit easy access by maintenance personnel and equipment. Access easements or rights-of-way are required for operation and should be designed for use during both dry and wet weather. In the case of privately maintained stormwater management facilities, every effort should be taken to ensure the responsible party and successors are made aware of the facilities maintenance requirements. Appropriate permits shall be obtained from resource agencies to allow the facilities to be maintained to the conditions used in the design. The lack of a regularly scheduled



Mapped Floodplains in San Diego County

FIGURE

1-4

Figure 1-4, page 2 of 2 color
"Mapped Floodplains in San Diego County"

Flood Control Facilities

FIGURE

1-5

Figure 1-5, page 2 of 2 color
"Flood Control Facilities"

program of maintenance is a factor that reduces the effectiveness of a stormwater control system and often results in adverse environmental impacts that may be difficult and costly to correct. Local agencies should be consulted to determine maintenance requirements. (Reference: American Public Works Association, Urban Stormwater Management, Special Report No. 49, Chicago, IL, 1981.)

1.2.1.3 Preparation for Floods

Flood Insurance

Most of the cities and the County of San Diego participate in the National Flood Insurance Program (NFIP) through FEMA. Any citizen in a participating community can purchase flood insurance for their home and/or the contents of their structure. Most insurance companies make flood policies available to their customers.

Real Time Rain and Reservoir Monitoring during Flood Periods

The Automatic Local Evaluation in Real Time (ALERT) System is a flood warning system that reports real-time rainfall and water levels at dams and rivers. Radios transmit information to the base station located in the DPWFCS office and the NWS office in Rancho Bernardo (Figure 1-6). DPWFCS personnel coordinate closely with the Office of Disaster Preparedness (ODP) and the NWS during periods of major storms to provide information about magnitudes and locations of flooding. The DPWFCS developed the first countywide ALERT system in California and is responsible for ongoing maintenance and operation (Figure 1-7). The ALERT system is coordinated with the data collection and analysis program that provides the data that is the basis for this manual.

1.3 INTENDED USE

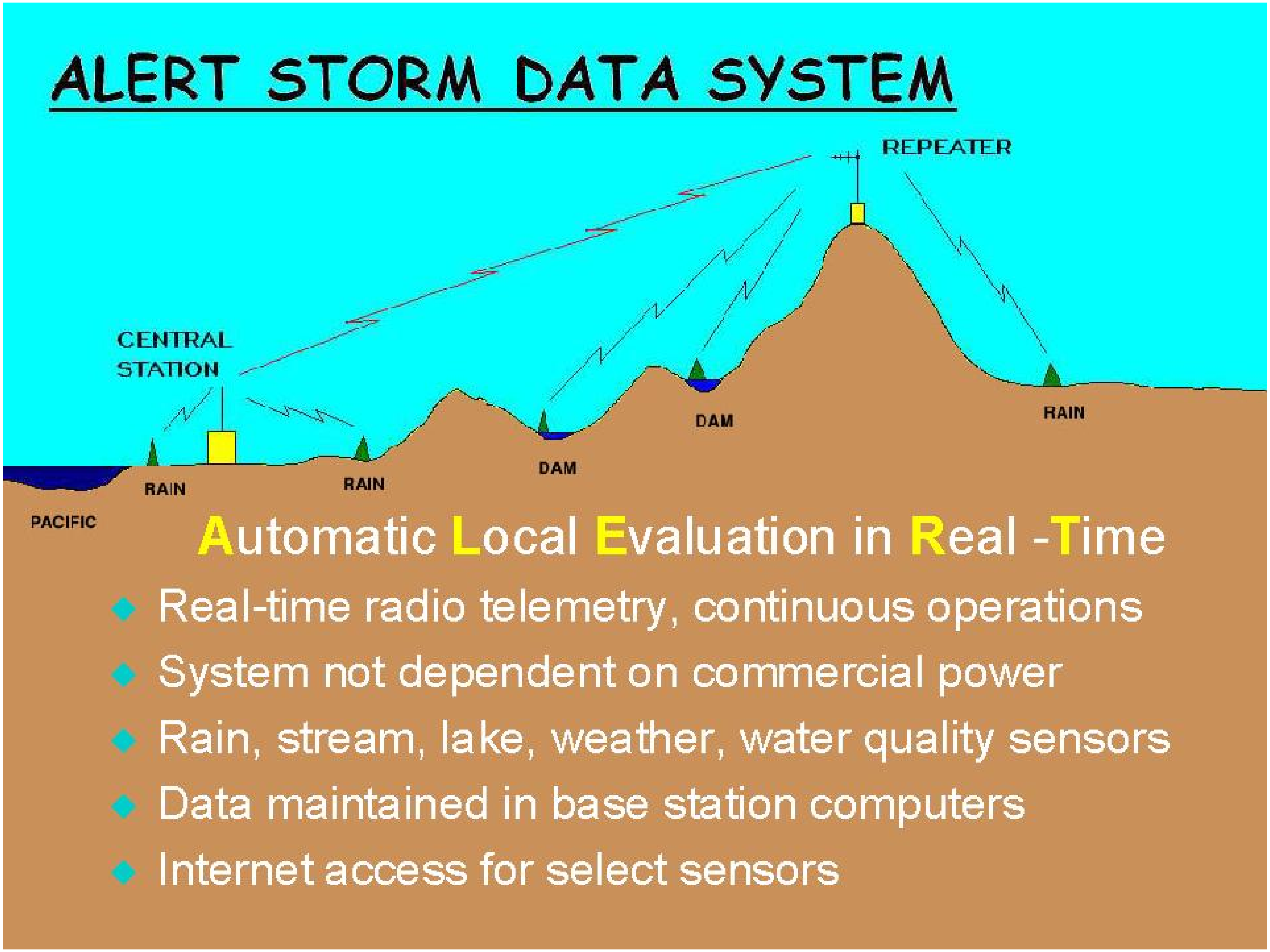
This manual should not be used when there is already an established flood flow. (Refer to Section 2 to determine whether an established flood flow exists.) If there is an established flood flow, it is important that the user work with the governing municipality to determine if the existing flood flow needs to be modified.

This manual is for general use within San Diego County and may be used by consultants, government agencies, resource agencies, planners, engineers, attorneys, and developers. The procedures presented herein are for guidance only and are to be used at the designer's own risk. The DPWFCS reserves the right to reject any or all computations. Each governing municipality should be consulted regarding the use of this manual.

1.4 ORGANIZATION OF MANUAL

This manual is organized into eight sections. Section 1 is the introduction to the manual and includes background information and a flowchart of the review process. Section 2 details other sources of established flood flow information.

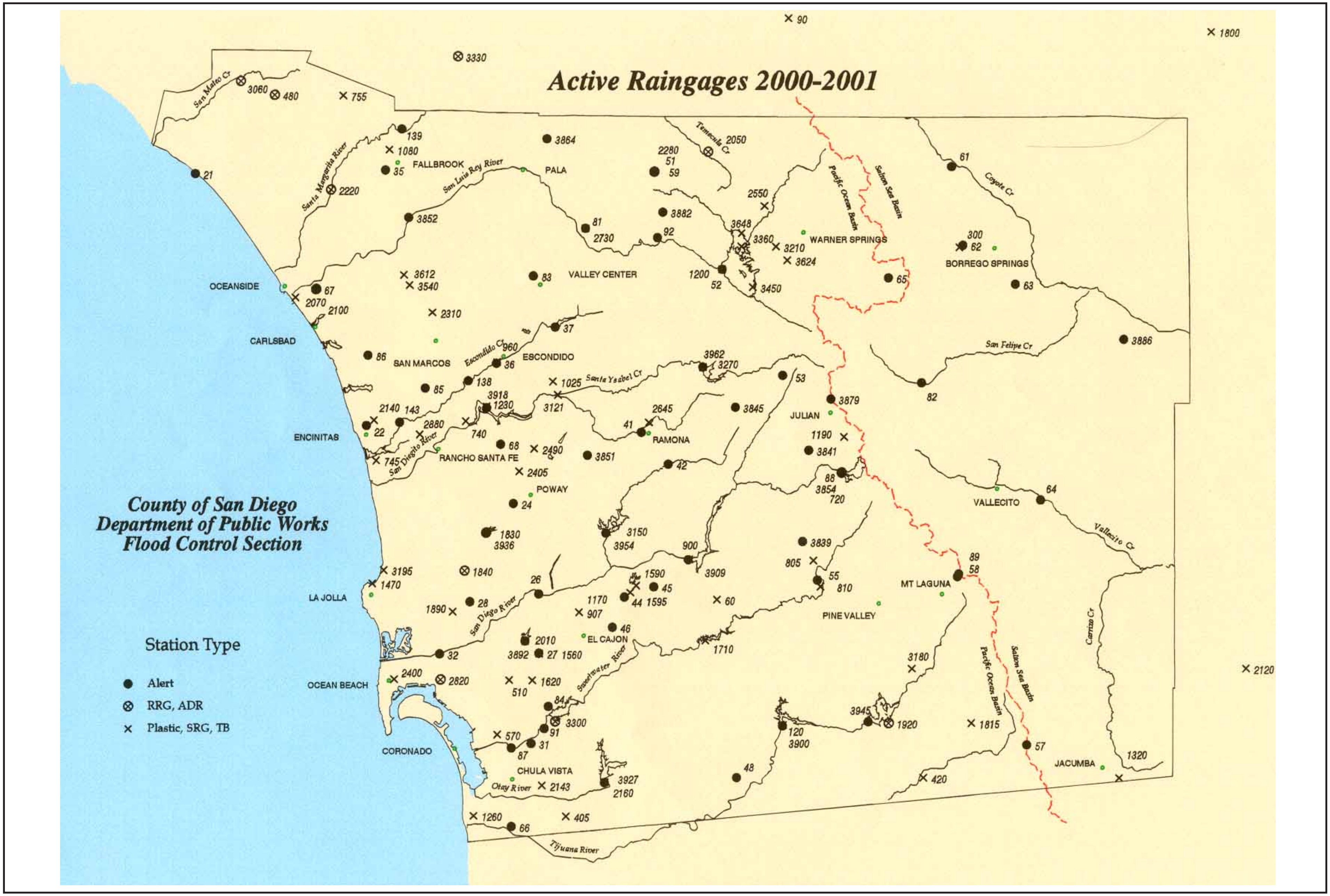
Section 3 discusses the Rational Method and Modified Rational Method. Section 4 discusses the NRCS hydrologic method. Please note that in Sections 3 and 4 the concept of infiltration is not covered. It is only on rare occasions that the engineer needs to adjust for infiltration. Always check with the agency of jurisdiction before incorporating an infiltration adjustment into any calculations. Section 5 addresses erosion and sedimentation. Section 6 discusses hydrographs created based on Rational Method and Modified Rational Method study results. Section 7 addresses water quality considerations as they relate to hydrology. Finally, Section 8 is dedicated to the bibliography for this manual. Whenever possible, figures and examples have been included in the sections to clarify the procedures. In each section, the use of applicable computer programs is discussed.



Alert Storm Data System

FIGURE 1-6

Figure 1-6, page 2 of 2 color
"ALERT Storm Data System"



Active Raingages 2000 - 2001

FIGURE 1-7

Figure 1-7, page 2 of 2 color
"Active Raingages 2000-2001"

1.5 Data Available from the County of San Diego Department of Public Works Flood Control Section

The DPWFCS maintains a long-term program of hydrologic data collection and recording, including rainfall, streamflow, erosion, and groundwater data. These data are maintained by the DPWFCS in a single data bank and analyzed to derive hydrologic parameters for use in the various simulation models and for other flood control purposes, such as flood warning systems.

The DPWFCS also maintains maps prepared by the NRCS showing hydrologic parameters. The maps most directly applicable to flood flow computations are the hydrologic soil group maps and the ground cover maps. Other maps, such as those showing erosion and brush conversion, are also used for flood flow computations.

A major function of the DPWFCS is the coordination of the flood control projects with the studies of other agencies. This coordination allows for consistent results. The County of San Diego has done a considerable amount of work with floodplain studies and flood control designs. These existing studies may be used as a reference (see Section 2).

1.6 Drainage Report Requirements and Components

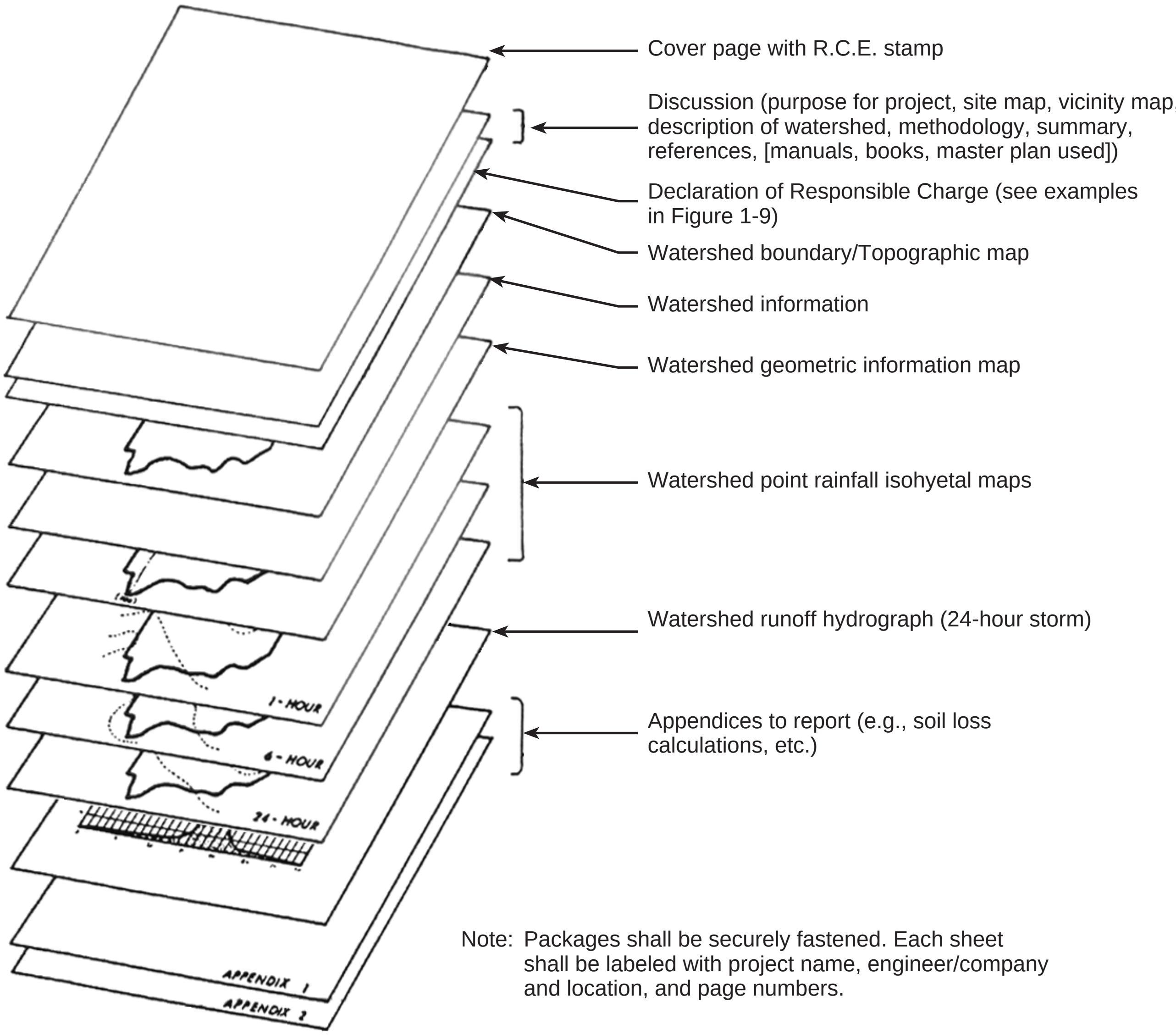
Drainage reports should follow the guidelines indicated in Figure 1-8 when using the Unit Hydrograph Method and revised to support calculations using other methods such as the Rational Method. Examples of acceptable Declarations of Responsible Charge are presented in Figure 1-9.

1.7 Use of Computer Programs

Any computer program used to support an engineer's calculations in preparation of a hydrology report should include good documentation of the calculations. The report should document information including input, steps followed, and key maps used. The output from the program's calculations should be presented in summary but also in detail in the report. The goal of the documentation is to clearly present the operations performed by the computer. Check with the local jurisdiction before using any software to determine its applicability.

The following public domain programs are acceptable:

- United States Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC): *Flood Hydrograph Package (HEC-1)*
- Natural Resources Conservation Service (NRCS) Technical Release Number 20: *TR-20, Project Formulation – Hydrology*
- USACE HEC: *Hydrologic Modeling System HEC-HMS*



Note: Packages shall be securely fastened. Each sheet shall be labeled with project name, engineer/company and location, and page numbers.

Required Report Format for Unit Hydrograph Study
San Diego County Hydrology Manual

FIGURE

1-8

DECLARATION OF RESPONSIBLE CHARGE:

I HEREBY DECLARE THAT I AM THE ENGINEER OF WORK FOR THIS PROJECT, THAT I HAVE EXERCISED RESPONSIBLE CHARGE OVER THE DESIGN OF THE PROJECT AS DEFINED IN SECTION 6703 OF THE BUSINESS AND PROFESSIONS CODE, AND THAT THE DESIGN IS CONSISTENT WITH CURRENT STANDARDS.

I UNDERSTAND THAT THE CHECK OF PROJECT DRAWINGS AND SPECIFICATIONS BY THE CITY OF SAN DIEGO IS CONFINED TO A REVIEW ONLY AND DOES NOT RELIEVE ME, AS ENGINEER OF WORK, OF MY RESPONSIBILITIES FOR PROJECT DESIGN.

REGISTERED PROFESSIONAL ENGINEER
MICHAEL L. SMITH
R.C.E. 35471
Exp. 9-30-03
CIVIL
STATE OF CALIFORNIA

ENGINEER OF WORK:

SAN DIEGO LAND SURVEYING & ENGINEERING, INC.
9619 CHESAPEAKE DRIVE, SUITE 204
SAN DIEGO, CALIFORNIA 92123
PHONE: (858) 565-8362
PROJECT NO. 452-214-56
ROBINSON-1TS.DWG

03-01-2001
MICHAEL L. SMITH, R.C.E. 35471 DATE
REGISTRATION EXPIRES SEPTEMBER 30, 2003

DECLARATION OF RESPONSIBLE CHARGE

I, HEREBY DECLARE THAT I AM THE CIVIL ENGINEER OF WORK FOR THIS PROJECT, THAT I HAVE EXERCISED RESPONSIBLE CHARGE OVER THE DESIGN OF THE PROJECT AS DEFINED IN SECTION 6703 OF THE BUSINESS AND PROFESSIONS CODE, AND THAT THE DESIGN IS CONSISTENT WITH CURRENT DESIGN.

I UNDERSTAND THAT THE CHECK OF PROJECT DRAWINGS AND SPECIFICATIONS BY THE CITY OF SAN DIEGO IS CONFINED TO A REVIEW ONLY AND DOES NOT RELIEVE ME, AS ENGINEER OF WORK, OF MY RESPONSIBILITIES FOR PROJECT DESIGN.

EDWIN E. PEACE DATE
R.C.E. 37586
EXP. 9-30-04

DECLARATION OF RESPONSIBLE CHARGE

I HEREBY DECLARE THAT I AM THE ENGINEER OF WORK FOR THIS PROJECT. THAT I HAVE EXERCISED RESPONSIBLE CHARGE OVER THE DESIGN OF THE PROJECT AS DEFINED IN SECTION 6703 OF THE BUSINESS AND PROFESSIONS CODE, AND THAT THE DESIGN IS CONSISTENT WITH CURRENT STANDARDS.

I UNDERSTAND THAT THE CHECK OF PROJECT DRAWINGS AND SPECIFICATIONS BY THE CITY OF SAN DIEGO IS CONFINED TO A REVIEW ONLY AND DOES NOT RELIEVE ME, AS ENGINEER OF WORK, OF MY RESPONSIBILITIES FOR PROJECT DESIGN.

3-27-2001
M. SCOTT LILLIBRIDGE R.C.E. 52504 DATE

REGISTERED PROFESSIONAL ENGINEER
M. SCOTT LILLIBRIDGE
No. 52504
Exp. 12\31\02
CIVIL
STATE OF CALIFORNIA

FIGURE 1-9

Example Declarations of Responsible Charge

SECTION 2
REGIONAL FLOOD FLOW INFORMATION AND SELECTION OF HYDROLOGIC METHOD AND DESIGN CRITERIA

2.1 REGIONAL FLOOD FLOW INFORMATION

Political entities are responsible for establishing and regulating flood control functions. In most watersheds of major size or importance (especially urban areas) flood flows are already established through one or more of the following activities.

1. Master Plan Development – The County of San Diego and the cities within the county have established master plans, most of which have been in effect for many years. For example, the County adopted the Comprehensive Flood Control and Drainage Plans in the mid-1970s. These plans have been updated at various times.

2. Studies for Development and Road Projects – These studies provide the basis for the design of projects such as channels and pipes, which are included in a major project. Once approved by a city or the County of San Diego, the flood flows form a basis for other nearby projects.

3. Flood Insurance Studies (FIS) – Rivers and creeks that have floodplain or alluvial fan maps may be identified through the Flood Insurance Study for San Diego County. The Corps used the flood flow frequency analysis for FIS in the 1970s. The Corps also used the frequency analysis method for the smaller flows and a rain/runoff analysis method to determine flows for the larger recurrence intervals. These maps and related information (including flood flows) are usually available at the offices of the political entity (city or county) that has land use jurisdiction. The local government and FEMA must approve any modification to the established flood flows.

It is important to review the land use basis for the FEMA hydrology studies. The studies are based on the existing land use at the time the study was completed. Since many of the FEMA maps were prepared in 1970, urbanization may have caused increased flows.

FEMA maps can be viewed at the SanGIS Web site (<www.sangis.org>). Maps may be viewed and printed with various overlays such as FEMA panels, roads, city boundaries, and property parcel boundaries.

4. Recorded Flows – The United States Geological Survey (USGS) and the County of San Diego have measured flows during flood events. A major source of information is the 1916 FLOOD publication by the USGS (available at DPWFCS). The USGS measured flood flows at numerous locations. The 1916 flood was the largest flood event of the twentieth century. The appendix to the State of California publication, Bulletin 112, also provides extensive recorded flood data.

2.2 TYPES OF HYDROGRAPHS

This classification is a partial list, suitable for use in watershed work.

1. Natural hydrographs. Obtained directly from the flow records of a gauged stream.
2. Synthetic hydrographs. Obtained by using watershed parameters and storm characteristics to simulate a natural hydrograph.
3. Unit hydrograph. A natural or synthetic hydrograph for 1 inch of excess rainfall. The excess rainfall is assumed to occur uniformly over the watershed in a specified time.
4. Dimensionless hydrograph. Made to represent many unit hydrographs by using the T_p and the peak discharge rates as basic units and plotting the hydrographs in ratios of these units. Also called index hydrograph.

2.3 SELECTION OF HYDROLOGIC METHOD AND DESIGN CRITERIA

Design Frequency – The flood frequency for determining the design storm discharge is 50 years for drainage that is upstream of any major roadway and 100 years frequency for all design storms at a major roadway, crossing the major roadway and thereafter. The 50-year storm flows shall be contained within the pipe and not encroach into the travel lane. For the 100-year storm this includes allowing one lane of a four-lane road (four or more lanes) to be used for conveyance without encroaching onto private property outside the dedicated street right-of-way. Natural channels that remain natural within private property are excluded from the right-of-way guideline.

Design Method – The choice of method to determine flows (discharge) shall be based on the size of the watershed area. For an area 0 to approximately 1 square mile the Rational Method or the Modified Rational Method shall be used. For watershed areas larger than 1 square mile the NRCS hydrologic method shall be used. Please check with the governing agency for any variations to these guidelines.

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SECTION 3
RATIONAL METHOD AND MODIFIED RATIONAL METHOD

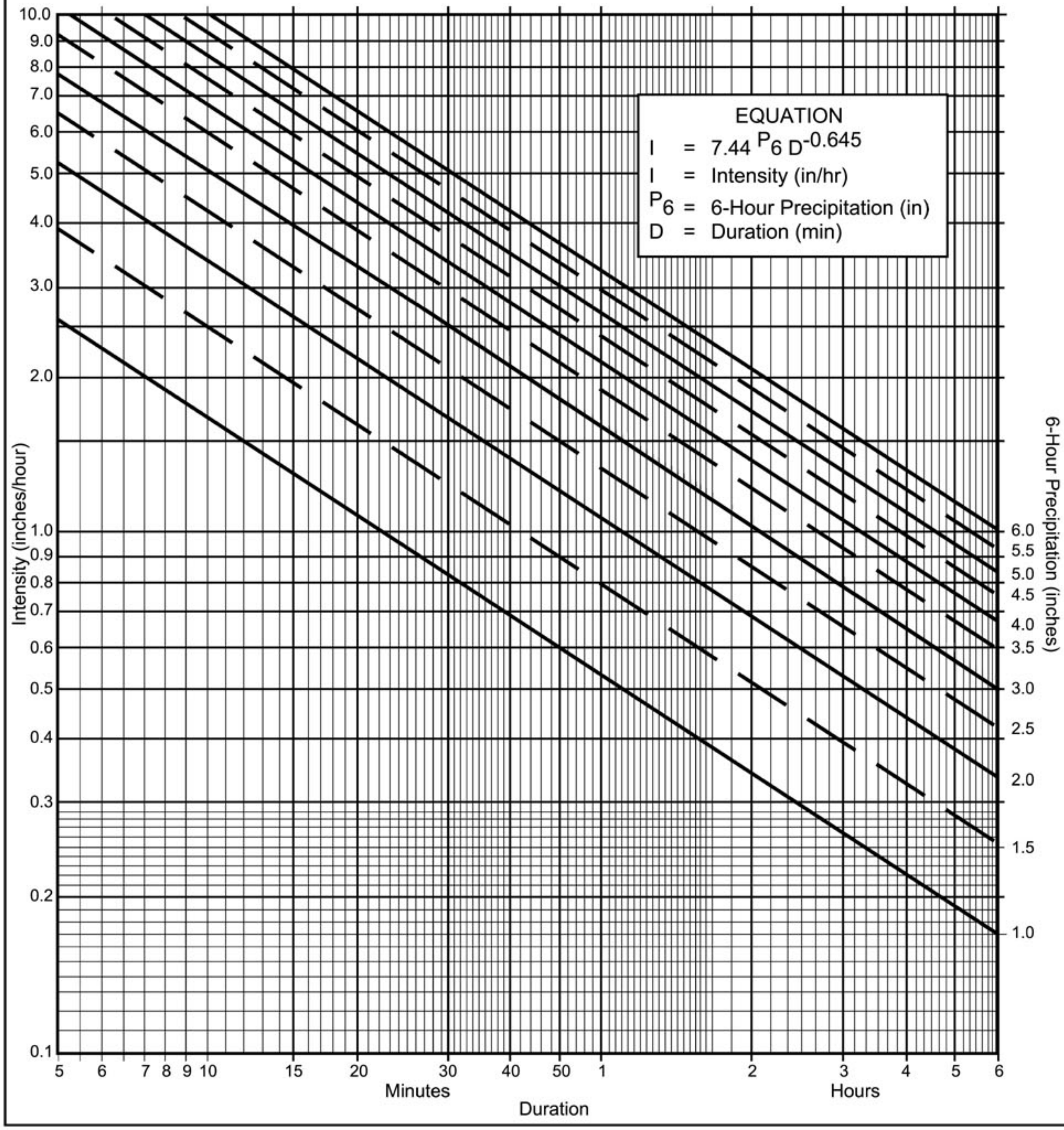
3.1 THE RATIONAL METHOD

The Rational Method (RM) is a mathematical formula used to determine the maximum runoff rate from a given rainfall. It has particular application in urban storm drainage, where it is used to estimate peak runoff rates from small urban and rural watersheds for the design of storm drains and small drainage structures. The RM is recommended for analyzing the runoff response from drainage areas up to approximately 1 square mile in size. It should not be used in instances where there is a junction of independent drainage systems or for drainage areas greater than approximately 1 square mile in size. In these instances, the Modified Rational Method (MRM) should be used for junctions of independent drainage systems in watersheds up to approximately 1 square mile in size (see Section 3.4); or the NRCS Hydrologic Method should be used for watersheds greater than approximately 1 square mile in size (see Section 4).

The RM can be applied using any design storm frequency (e.g., 100-year, 50-year, 10-year, etc.). The local agency determines the design storm frequency that must be used based on the type of project and specific local requirements. A discussion of design storm frequency is provided in Section 2.3 of this manual. A procedure has been developed that converts the 6-hour and 24-hour precipitation isopluvial map data to an Intensity-Duration curve that can be used for the rainfall intensity in the RM formula as shown in Figure 3-1. The RM is applicable to a 6-hour storm duration because the procedure uses Intensity-Duration Design Charts that are based on a 6-hour storm duration.

3.1.1 Rational Method Formula

The RM formula estimates the peak rate of runoff at any location in a watershed as a function of the drainage area (A), runoff coefficient (C), and rainfall intensity (I) for a duration equal to the time of concentration (T_c), which is the time required for water to



Directions for Application:

(1) From precipitation maps determine 6 hr and 24 hr amounts for the selected frequency. These maps are included in the County Hydrology Manual (10, 50, and 100 yr maps included in the Design and Procedure Manual).

(2) Adjust 6 hr precipitation (if necessary) so that it is within the range of 45% to 65% of the 24 hr precipitation (not applicable to Desert).

(3) Plot 6 hr precipitation on the right side of the chart.

(4) Draw a line through the point parallel to the plotted lines.

(5) This line is the intensity-duration curve for the location being analyzed.

Application Form:

(a) Selected frequency ______ year

(b) P_6 = ______ in., P_{24} = ______, $\frac{P_6}{P_{24}}$ = ______ %(2)

(c) Adjusted $P_6^{(2)}$ = ______ in.

(d) t_x = ______ min.

(e) I = ______ in./hr.

Note: This chart replaces the Intensity-Duration-Frequency curves used since 1965.

P6	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
Duration	I	I	I	I	I	I	I	I	I	I	I
5	2.63	3.95	5.27	6.59	7.90	9.22	10.54	11.86	13.17	14.49	15.81
7	2.12	3.18	4.24	5.30	6.36	7.42	8.48	9.54	10.60	11.66	12.72
10	1.68	2.53	3.37	4.21	5.05	5.90	6.74	7.58	8.42	9.27	10.11
15	1.30	1.95	2.59	3.24	3.89	4.54	5.19	5.84	6.49	7.13	7.78
20	1.08	1.62	2.15	2.69	3.23	3.77	4.31	4.85	5.39	5.93	6.46
25	0.93	1.40	1.87	2.33	2.80	3.27	3.73	4.20	4.67	5.13	5.60
30	0.83	1.24	1.66	2.07	2.49	2.90	3.32	3.73	4.15	4.56	4.98
40	0.69	1.03	1.38	1.72	2.07	2.41	2.76	3.10	3.45	3.79	4.13
50	0.60	0.90	1.19	1.49	1.79	2.09	2.39	2.69	2.98	3.28	3.58
60	0.53	0.80	1.06	1.33	1.59	1.86	2.12	2.39	2.65	2.92	3.18
90	0.41	0.61	0.82	1.02	1.23	1.43	1.63	1.84	2.04	2.25	2.45
120	0.34	0.51	0.68	0.85	1.02	1.19	1.36	1.53	1.70	1.87	2.04
150	0.29	0.44	0.59	0.73	0.88	1.03	1.18	1.32	1.47	1.62	1.76
180	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.18	1.31	1.44	1.57
240	0.22	0.33	0.43	0.54	0.65	0.76	0.87	0.98	1.08	1.19	1.30
300	0.19	0.28	0.38	0.47	0.56	0.66	0.75	0.85	0.94	1.03	1.13
360	0.17	0.25	0.33	0.42	0.50	0.58	0.67	0.75	0.84	0.92	1.00

Intensity-Duration Design Chart - Template

FIGURE

3-1

flow from the most remote point of the basin to the location being analyzed. The RM formula is expressed as follows:

$$Q = C\ I\ A$$

Where: Q = peak discharge, in cubic feet per second (cfs)
C = runoff coefficient, proportion of the rainfall that runs off the surface (no units)
I = average rainfall intensity for a duration equal to the T_c for the area, in inches per hour (Note: If the computed T_c is less than 5 minutes, use 5 minutes for computing the peak discharge, Q)
A = drainage area contributing to the design location, in acres

Combining the units for the expression CIA yields:

$$\left(\frac{1\,\text{acre}\times\text{inch}}{\text{hour}}\right)\left(\frac{43{,}560\,\text{ft}^2}{\text{acre}}\right)\left(\frac{1\,\text{foot}}{12\,\text{inches}}\right)\left(\frac{1\,\text{hour}}{3{,}600\,\text{seconds}}\right) \Rightarrow 1.008\,\text{cfs}$$

For practical purposes the unit conversion coefficient difference of 0.8% can be ignored.

The RM formula is based on the assumption that for constant rainfall intensity, the peak discharge rate at a point will occur when the raindrop that falls at the most upstream point in the tributary drainage basin arrives at the point of interest.

Unlike the MRM (discussed in Section 3.4) or the NRCS hydrologic method (discussed in Section 4), the RM does not create hydrographs and therefore does not add separate subarea hydrographs at collection points. Instead, the RM develops peak discharges in the main line by increasing the T_c as flow travels downstream.

Characteristics of, or assumptions inherent to, the RM are listed below:

- The discharge flow rate resulting from any I is maximum when the I lasts as long as or longer than the T_c.

- The storm frequency of peak discharges is the same as that of I for the given T_c.

- The fraction of rainfall that becomes runoff (or the runoff coefficient, C) is independent of I or precipitation zone number (PZN) condition (PZN Condition is discussed in Section 4.1.2.4).

- The peak rate of runoff is the only information produced by using the RM.

3.1.2 Runoff Coefficient

Table 3-1 lists the estimated runoff coefficients for urban areas. The concepts related to the runoff coefficient were evaluated in a report entitled *Evaluation, Rational Method "C" Values* (Hill, 2002) that was reviewed by the Hydrology Manual Committee. The Report is available at San Diego County Department of Public Works, Flood Control Section and on the San Diego County Department of Public Works web page.

The runoff coefficients are based on land use and soil type. Soil type can be determined from the soil type map provided in Appendix A. An appropriate runoff coefficient (C) for each type of land use in the subarea should be selected from this table and multiplied by the percentage of the total area (A) included in that class. The sum of the products for all land uses is the weighted runoff coefficient (Σ[CA]). Good engineering judgment should be used when applying the values presented in Table 3-1, as adjustments to these values may be appropriate based on site-specific characteristics. In any event, the impervious percentage (% Impervious) as given in the table, for any area, shall govern the selected value for C. The runoff coefficient can also be calculated for an area based on soil type and impervious percentage using the following formula:

$$C = 0.90 \times (\% \text{ Impervious}) + C_p \times (1 - \% \text{ Impervious})$$

Where: C_p = Pervious Coefficient Runoff Value for the soil type (shown in Table 3-1 as Undisturbed Natural Terrain/Permanent Open Space, 0% Impervious). Soil type can be determined from the soil type map provided in Appendix A.

The values in Table 3-1 are typical for most urban areas. However, if the basin contains rural or agricultural land use, parks, golf courses, or other types of nonurban land use that are expected to be permanent, the appropriate value should be selected based upon the soil and cover and approved by the local agency.

Table 3-1
RUNOFF COEFFICIENTS FOR URBAN AREAS

Land Use		Runoff Coefficient "C"				
			Soil Type			
NRCS Elements	County Elements	% IMPER.	A	B	C	D
Undisturbed Natural Terrain (Natural)	Permanent Open Space	0*	0.20	0.25	0.30	0.35
Low Density Residential (LDR)	Residential, 1.0 DU/A or less	10	0.27	0.32	0.36	0.41
Low Density Residential (LDR)	Residential, 2.0 DU/A or less	20	0.34	0.38	0.42	0.46
Low Density Residential (LDR)	Residential, 2.9 DU/A or less	25	0.38	0.41	0.45	0.49
Medium Density Residential (MDR)	Residential, 4.3 DU/A or less	30	0.41	0.45	0.48	0.52
Medium Density Residential (MDR)	Residential, 7.3 DU/A or less	40	0.48	0.51	0.54	0.57
Medium Density Residential (MDR)	Residential, 10.9 DU/A or less	45	0.52	0.54	0.57	0.60
Medium Density Residential (MDR)	Residential, 14.5 DU/A or less	50	0.55	0.58	0.60	0.63
High Density Residential (HDR)	Residential, 24.0 DU/A or less	65	0.66	0.67	0.69	0.71
High Density Residential (HDR)	Residential, 43.0 DU/A or less	80	0.76	0.77	0.78	0.79
Commercial/Industrial (N. Com)	Neighborhood Commercial	80	0.76	0.77	0.78	0.79
Commercial/Industrial (G. Com)	General Commercial	85	0.80	0.80	0.81	0.82
Commercial/Industrial (O.P. Com)	Office Professional/Commercial	90	0.83	0.84	0.84	0.85
Commercial/Industrial (Limited I.)	Limited Industrial	90	0.83	0.84	0.84	0.85
Commercial/Industrial (General I.)	General Industrial	95	0.87	0.87	0.87	0.87

*The values associated with 0% impervious may be used for direct calculation of the runoff coefficient as described in Section 3.1.2 (representing the pervious runoff coefficient, Cp, for the soil type), or for areas that will remain undisturbed in perpetuity. Justification must be given that the area will remain natural forever (e.g., the area is located in Cleveland National Forest).
DU/A = dwelling units per acre
NRCS = National Resources Conservation Service

3.1.3 Rainfall Intensity

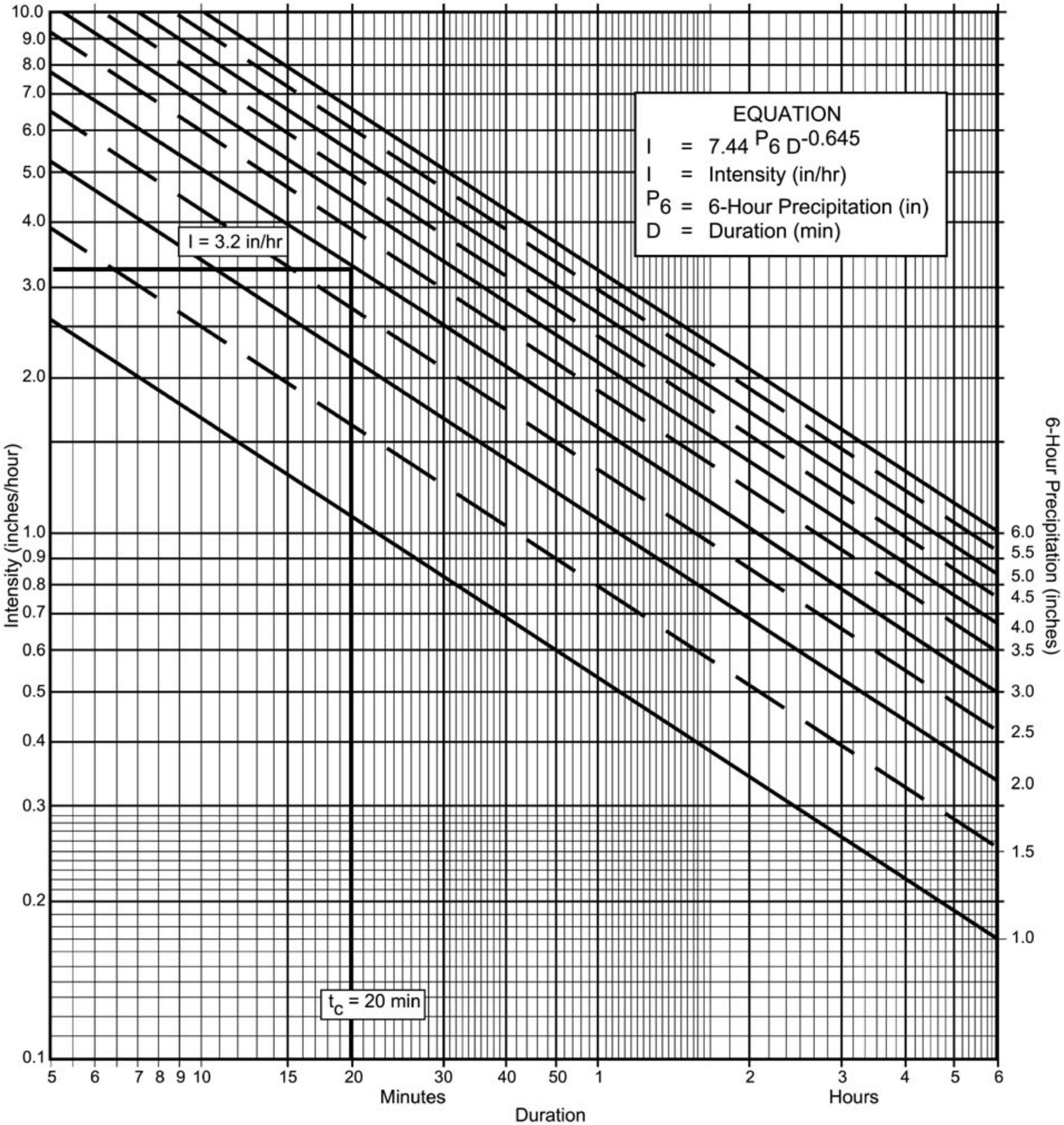
The rainfall intensity (I) is the rainfall in inches per hour (in/hr) for a duration equal to the T_c for a selected storm frequency. Once a particular storm frequency has been selected for design and a T_c calculated for the drainage area, the rainfall intensity can be determined from the Intensity-Duration Design Chart (Figure 3-1). The 6-hour storm rainfall amount (P_6) and the 24-hour storm rainfall amount (P_{24}) for the selected storm frequency are also needed for calculation of I. P_6 and P_{24} can be read from the isopluvial maps provided in Appendix B. An Intensity-Duration Design Chart applicable to all areas within San Diego County is provided as Figure 3-1. Figure 3-2 provides an example of use of the Intensity-Duration Design Chart. Intensity can also be calculated using the following equation:

$$I = 7.44\ P_6\ D^{-0.645}$$

Where: P_6 = adjusted 6-hour storm rainfall amount (see discussion below)
D = duration in minutes (use T_c)

Note: This equation applies only to the 6-hour storm rainfall amount (i.e., P_6 cannot be changed to P_{24} to calculate a 24-hour intensity using this equation).

The Intensity-Duration Design Chart and the equation are for the 6-hour storm rainfall amount. In general, P_6 for the selected frequency should be between 45% and 65% of P_{24} for the selected frequency. If P_6 is not within 45% to 65% of P_{24}, P_6 should be increased or decreased as necessary to meet this criteria. The isopluvial lines are based on precipitation gauge data. At the time that the isopluvial lines were created, the majority of precipitation gauges in San Diego County were read daily, and these readings yielded 24-hour precipitation data. Some 6-hour data were available from the few recording gauges distributed throughout the County at that time; however, some 6-hour data were extrapolated. Therefore, the 24-hour precipitation data for San Diego County are considered to be more reliable.



Directions for Application:

(1) From precipitation maps determine 6 hr and 24 hr amounts for the selected frequency. These maps are included in the County Hydrology Manual (10, 50, and 100 yr maps included in the Design and Procedure Manual).

(2) Adjust 6 hr precipitation (if necessary) so that it is within the range of 45% to 65% of the 24 hr precipitation (not applicable to Desert).

(3) Plot 6 hr precipitation on the right side of the chart.

(4) Draw a line through the point parallel to the plotted lines.

(5) This line is the intensity-duration curve for the location being analyzed.

Application Form:

(a) Selected frequency <u>50</u> year

(b) P_6 = <u>3</u> in., P_{24} = <u>5.5</u>, $\frac{P_6}{P_{24}}$ = <u>54.5</u> %(2)

(c) Adjusted $P_6^{(2)}$ = <u>3</u> in.

(d) t_x = <u>20</u> min.

(e) I = <u>3.2</u> in./hr.

Note: This chart replaces the Intensity-Duration-Frequency curves used since 1965.

P6	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
Duration	I	I	I	I	I	I	I	I	I	I	I
5	2.63	3.95	5.27	6.59	7.90	9.22	10.54	11.86	13.17	14.49	15.81
7	2.12	3.18	4.24	5.30	6.36	7.42	8.48	9.54	10.60	11.66	12.72
10	1.68	2.53	3.37	4.21	5.05	5.90	6.74	7.58	8.42	9.27	10.11
15	1.30	1.95	2.59	3.24	3.89	4.54	5.19	5.84	6.49	7.13	7.78
20	1.08	1.62	2.15	2.69	3.23	3.77	4.31	4.85	5.39	5.93	6.46
25	0.93	1.40	1.87	2.33	2.80	3.27	3.73	4.20	4.67	5.13	5.60
30	0.83	1.24	1.66	2.07	2.49	2.90	3.32	3.73	4.15	4.56	4.98
40	0.69	1.03	1.38	1.72	2.07	2.41	2.76	3.10	3.45	3.79	4.13
50	0.60	0.90	1.19	1.49	1.79	2.09	2.39	2.69	2.98	3.28	3.58
60	0.53	0.80	1.06	1.33	1.59	1.86	2.12	2.39	2.65	2.92	3.18
90	0.41	0.61	0.82	1.02	1.23	1.43	1.63	1.84	2.04	2.25	2.45
120	0.34	0.51	0.68	0.85	1.02	1.19	1.36	1.53	1.70	1.87	2.04
150	0.29	0.44	0.59	0.73	0.88	1.03	1.18	1.32	1.47	1.62	1.76
180	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.18	1.31	1.44	1.57
240	0.22	0.33	0.43	0.54	0.65	0.76	0.87	0.98	1.08	1.19	1.30
300	0.19	0.28	0.38	0.47	0.56	0.66	0.75	0.85	0.94	1.03	1.13
360	0.17	0.25	0.33	0.42	0.50	0.58	0.67	0.75	0.84	0.92	1.00

Intensity-Duration Design Chart - Example

FIGURE

3-2

3.1.4 Time of Concentration

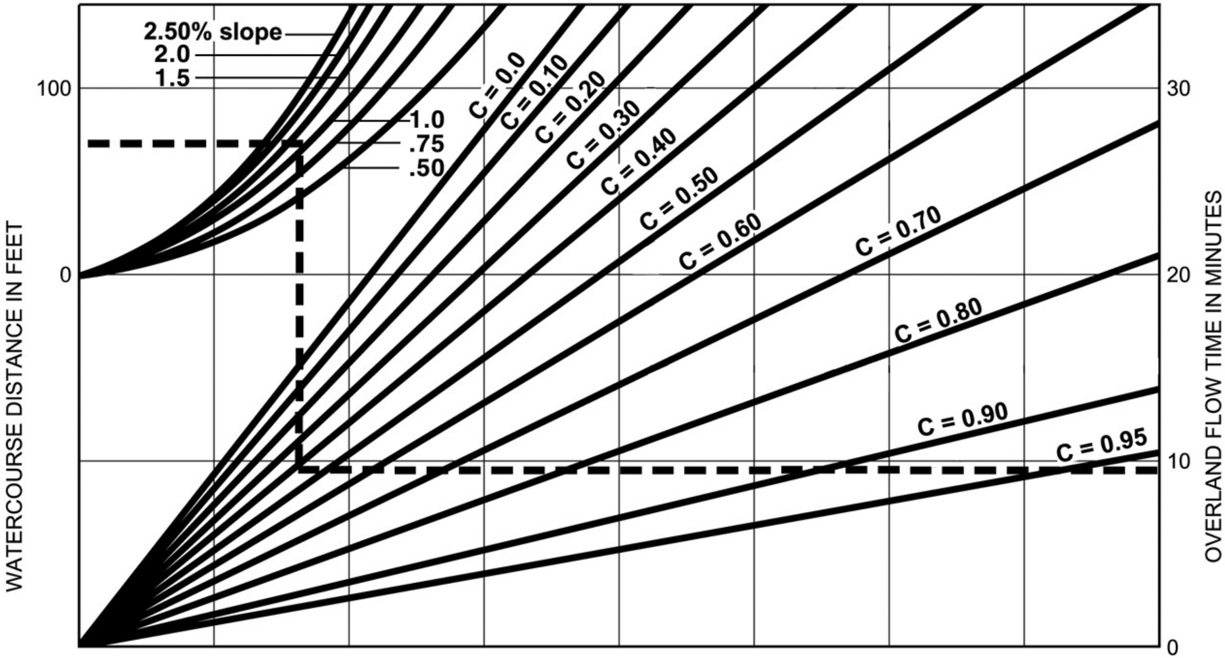
The Time of Concentration (T_c) is the time required for runoff to flow from the most remote part of the drainage area to the point of interest. The T_c is composed of two components: initial time of concentration (T_i) and travel time (T_t). Methods of computation for T_i and T_t are discussed below. The T_i is the time required for runoff to travel across the surface of the most remote subarea in the study, or "initial subarea." Guidelines for designating the initial subarea are provided within the discussion of computation of T_i. The T_t is the time required for the runoff to flow in a watercourse (e.g., swale, channel, gutter, pipe) or series of watercourses from the initial subarea to the point of interest. For the RM, the T_c at any point within the drainage area is given by:

$$T_c = T_i + T_t$$

Methods of calculation differ for natural watersheds (nonurbanized) and for urban drainage systems. When analyzing storm drain systems, the designer must consider the possibility that an existing natural watershed may become urbanized during the useful life of the storm drain system. Future land uses must be used for T_c and runoff calculations, and can be determined from the local Community General Plan.

3.1.4.1 Initial Time of Concentration

The initial time of concentration is typically based on sheet flow at the upstream end of a drainage basin. The Overland Time of Flow (Figure 3-3) is approximated by an equation developed by the Federal Aviation Agency (FAA) for analyzing flow on runaways (FAA, 1970). The usual runway configuration consists of a crown, like most freeways, with sloping pavement that directs flow to either side of the runway. This type of flow is uniform in the direction perpendicular to the velocity and is very shallow. Since these depths are ¼ of an inch (more or less) in magnitude, the relative roughness is high. Some higher relative roughness values for overland flow are presented in Table 3.5 of the *HEC-1 Flood Hydrograph Package User's Manual* (USACE, 1990).



EXAMPLE:

Given: Watercourse Distance (D) = 70 Feet
Slope (s) = 1.3%
Runoff Coefficient (C) = 0.41
Overland Flow Time (T) = 9.5 Minutes

$$T = \frac{1.8\,(1.1-C)\sqrt{D}}{\sqrt[3]{s}}$$

SOURCE: Airport Drainage, Federal Aviation Administration, 1965

Rational Formula - Overland Time of Flow Nomograph

FIGURE

3-3

The sheet flow that is predicted by the FAA equation is limited to conditions that are similar to runway topography. Some considerations that limit the extent to which the FAA equation applies are identified below:

- Urban Areas – This "runway type" runoff includes:
  1) Flat roofs, sloping at 1% ±
  2) Parking lots at the extreme upstream drainage basin boundary (at the "ridge" of a catchment area).
     Even a parking lot is limited in the amounts of sheet flow. Parked or moving vehicles would "break-up" the sheet flow, concentrating runoff into streams that are not characteristic of sheet flow.
  3) Driveways are constructed at the upstream end of catchment areas in some developments. However, if flow from a roof is directed to a driveway through a downspout or other conveyance mechanism, flow would be concentrated.
  4) Flat slopes are prone to meandering flow that tends to be disrupted by minor irregularities and obstructions. Maximum Overland Flow lengths are shorter for the flatter slopes (see Table 3-2).

- Rural or Natural Areas - The FAA equation is applicable to these conditions since (.5% to 10%) slopes that are uniform in width of flow have slow velocities consistent with the equation. Irregularities in terrain limit the length of application.
  1) Most hills and ridge lines have a relatively flat area near the drainage divide. However, with flat slopes of .5% ±, minor irregularities would cause flow to concentrate into streams.
  2) Parks, lawns and other vegetated areas would have slow velocities that are consistent with the FAA Equation.

The concepts related to the initial time of concentration were evaluated in a report entitled *Initial Time of Concentration, Analysis of Parameters* (Hill, 2002) that was reviewed by the Hydrology Manual Committee. The Report is available at San Diego County Department of Public Works, Flood Control Section and on the San Diego County Department of Public Works web page.

Note that the Initial Time of Concentration should be reflective of the general land-use at the upstream end of a drainage basin. A single lot with an area of two or less acres does not have a significant effect where the drainage basin area is 20 to 600 acres.

Table 3-2 provides limits of the length (Maximum Length (L_M)) of sheet flow to be used in hydrology studies. Initial T_i values based on average C values for the Land Use Element are also included. These values can be used in planning and design applications as described below. Exceptions may be approved by the "Regulating Agency" when submitted with a detailed study.

Table 3-2

MAXIMUM OVERLAND FLOW LENGTH (L_M) & INITIAL TIME OF CONCENTRATION (T_i)

Element*	DU/ Acre	.5%		1%		2%		3%		5%		10%	
		L_M	T_i	L_M	T_i	L_M	T_i	L_M	T_i	L_M	T_i	L_M	T_i
Natural		50	13.2	70	12.5	85	10.9	100	10.3	100	8.7	100	6.9
LDR	1	50	12.2	70	11.5	85	10.0	100	9.5	100	8.0	100	6.4
LDR	2	50	11.3	70	10.5	85	9.2	100	8.8	100	7.4	100	5.8
LDR	2.9	50	10.7	70	10.0	85	8.8	95	8.1	100	7.0	100	5.6
MDR	4.3	50	10.2	70	9.6	80	8.1	95	7.8	100	6.7	100	5.3
MDR	7.3	50	9.2	65	8.4	80	7.4	95	7.0	100	6.0	100	4.8
MDR	10.9	50	8.7	65	7.9	80	6.9	90	6.4	100	5.7	100	4.5
MDR	14.5	50	8.2	65	7.4	80	6.5	90	6.0	100	5.4	100	4.3
HDR	24	50	6.7	65	6.1	75	5.1	90	4.9	95	4.3	100	3.5
HDR	43	50	5.3	65	4.7	75	4.0	85	3.8	95	3.4	100	2.7
N. Com		50	5.3	60	4.5	75	4.0	85	3.8	95	3.4	100	2.7
G. Com		50	4.7	60	4.1	75	3.6	85	3.4	90	2.9	100	2.4
O.P./Com		50	4.2	60	3.7	70	3.1	80	2.9	90	2.6	100	2.2
Limited I.		50	4.2	60	3.7	70	3.1	80	2.9	90	2.6	100	2.2
General I.		50	3.7	60	3.2	70	2.7	80	2.6	90	2.3	100	1.9

*See Table 3-1 for more detailed description

3.1.4.1A Planning Considerations

The purpose of most hydrology studies is to develop flood flow values for areas that are not at the upstream end of the basin. Another example is the Master Plan, which is usually completed before the actual detailed design of lots, streets, etc. are accomplished. In these situations it is necessary that the initial time of concentration be determined without detailed information about flow patterns.

To provide guidance for the initial time of concentration design parameters, Table 3-2 includes the Land Use Elements and other variables related to the Time of Concentration. The table development included a review of the typical "layout" of the different Land Use Elements and related flow patterns and consideration of the extent of the sheet flow regimen, the effect of ponding, the significance to the drainage basin, downstream effects, etc.

3.1.4.1B Computation Criteria

(a) Developed Drainage Areas With Overland Flow - T_i may be obtained directly from the chart, "Rational Formula – Overland Time of Flow Nomograph," shown in Figure 3-3 or from Table 3-2. This chart is based on the Federal Aviation Agency (FAA) equation (FAA, 1970). For the short rain durations (<15 minutes) involved, intensities are high but the depth of flooding is limited and much of the runoff is stored temporarily in the overland flow and in shallow ponded areas. In developed areas, overland flow is limited to lengths given in Table 3-2. Beyond these distances, flow tends to become concentrated into streets, gutters, swales, ditches, etc.

(b) Natural Or Rural Watersheds – These areas usually have an initial subarea at the upstream end with sheet flow. The sheet flow length is limited to 50 to 100 feet as specified in Table 3-2. The Overland Time of Flow Nomograph, Figure 3-3, can be used to obtain T_i. The initial time of concentration can excessively affect the magnitude of flow further downstream in the drainage basin. For instance, variations in the initial time of concentration for an initial subarea of one acre can change the flow further downstream where the area is 400 acres by 100%. Therefore, the initial time of concentration is limited (see Table 3-2).

The Rational Method procedure included in the original Hydrology Manual (1971) and Design and Procedure Manual (1968) included a 10 minute value to be added to the initial time of concentration developed through the Kirpich Formula (see Figure 3-4) for a natural watershed. That procedure is superceded by the procedure above to use Table 3-2 or Figure 3-3 to determine T_i for the appropriate sheet flow length of the initial subarea. The values for natural watersheds given in Table 3-2 vary from 13 to 7 minutes, depending on slope. If the total length of the initial subarea is greater than the maximum length allowable based on Table 3-2, add the travel time based on the Kirpich formula for the remaining length of the initial subarea.

3.1.4.2 Travel Time

The T_t is the time required for the runoff to flow in a watercourse (e.g., swale, channel, gutter, pipe) or series of watercourses from the initial subarea to the point of interest. The T_t is computed by dividing the length of the flow path by the computed flow velocity. Since the velocity normally changes as a result of each change in flow rate or slope, such as at an inlet or grade break, the total T_t must be computed as the sum of the T_t's for each section of the flow path. Use Figure 3-6 to estimate time of travel for street gutter flow. Velocity in a channel can be estimated by using the nomograph shown in Figure 3-7 (Manning's Equation Nomograph).

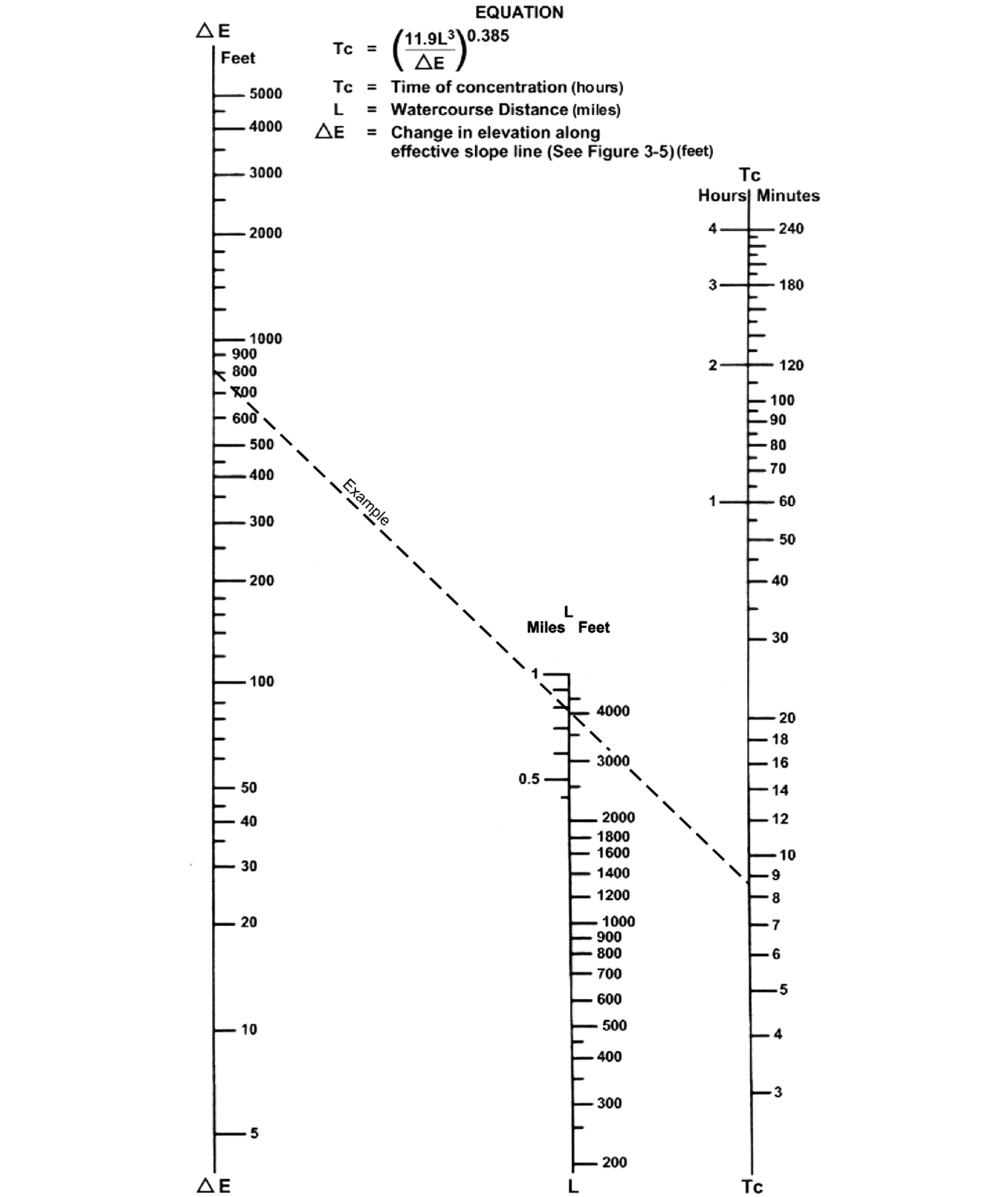
(a) Natural Watersheds – This includes rural, ranch, and agricultural areas with natural channels. Obtain T_t directly from the Kirpich nomograph in Figure 3-4 or from the equation. This nomograph requires values for length and change in elevation along the effective slope line for the subarea. See Figure 3-5 for a representation of the effective slope line.

This nomograph is based on the Kirpich formula, which was developed with data from agricultural watersheds ranging from 1.25 to 112 acres in area, 350 to 4,000 feet in length, and 2.7 to 8.8% slope (Kirpich, 1940). A maximum length of 4,000 feet should be used for the subarea length. Typically, as the flow length increases, the depth of flow will increase, and therefore it is considered a concentration of flow at points beyond lengths listed in Figure 3-2. However, because the Kirpich formula has been shown to be applicable for watersheds up to 4,000 feet in length (Kirpich, 1940), a subarea may be designated with a length up to 4,000 feet provided the topography and slope of the natural channel are generally uniform.

Justification needs to be included with this calculation showing that the watershed will remain natural forever. Examples include areas located in the Multiple Species Conservation Plan (MSCP), areas designated as open space or rural in a community's General Plan, and Cleveland National Forest.

(b) Urban Watersheds - Flow through a closed conduit where no additional flow can enter the system during the travel, length, velocity and T_t are determined using the peak flow in the conduit. In cases where the conduit is not closed and additional flow from a contributing subarea is added to the total flow during travel (e.g., street flow in a gutter), calculation of velocity and T_t is performed using an assumed average flow based on the total area (including upstream subareas) contributing to the point of interest. The Manning equation is usually used to determine velocity. Discharges for small watersheds typically range from 2 to 3 cfs per acre, depending on land use, drainage area, and slope and rainfall intensity.

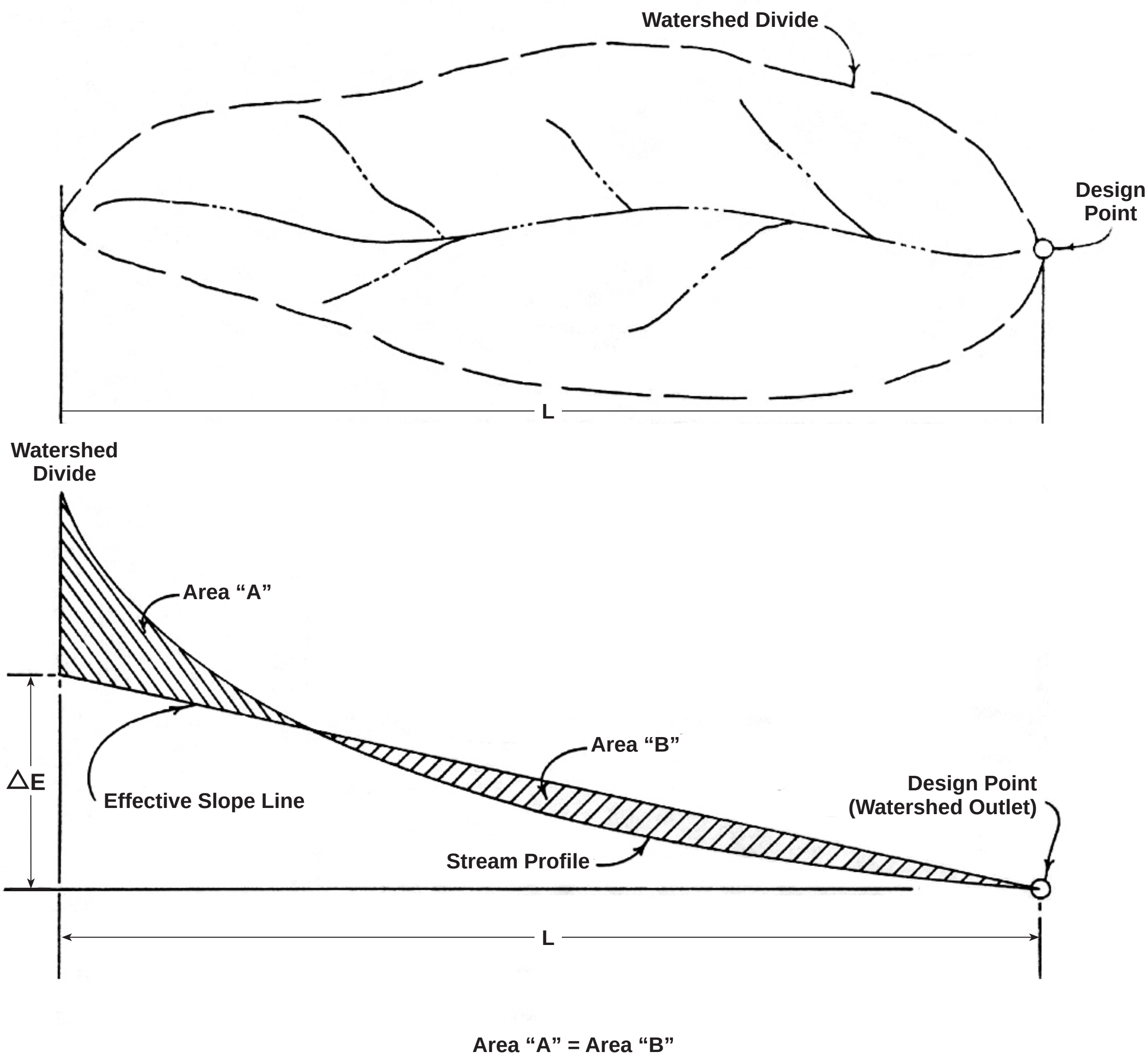
Note: The MRM should be used to calculate the peak discharge when there is a junction from independent subareas into the drainage system.



SOURCE: California Division of Highways (1941) and Kirpich (1940)

FIGURE **3-4**

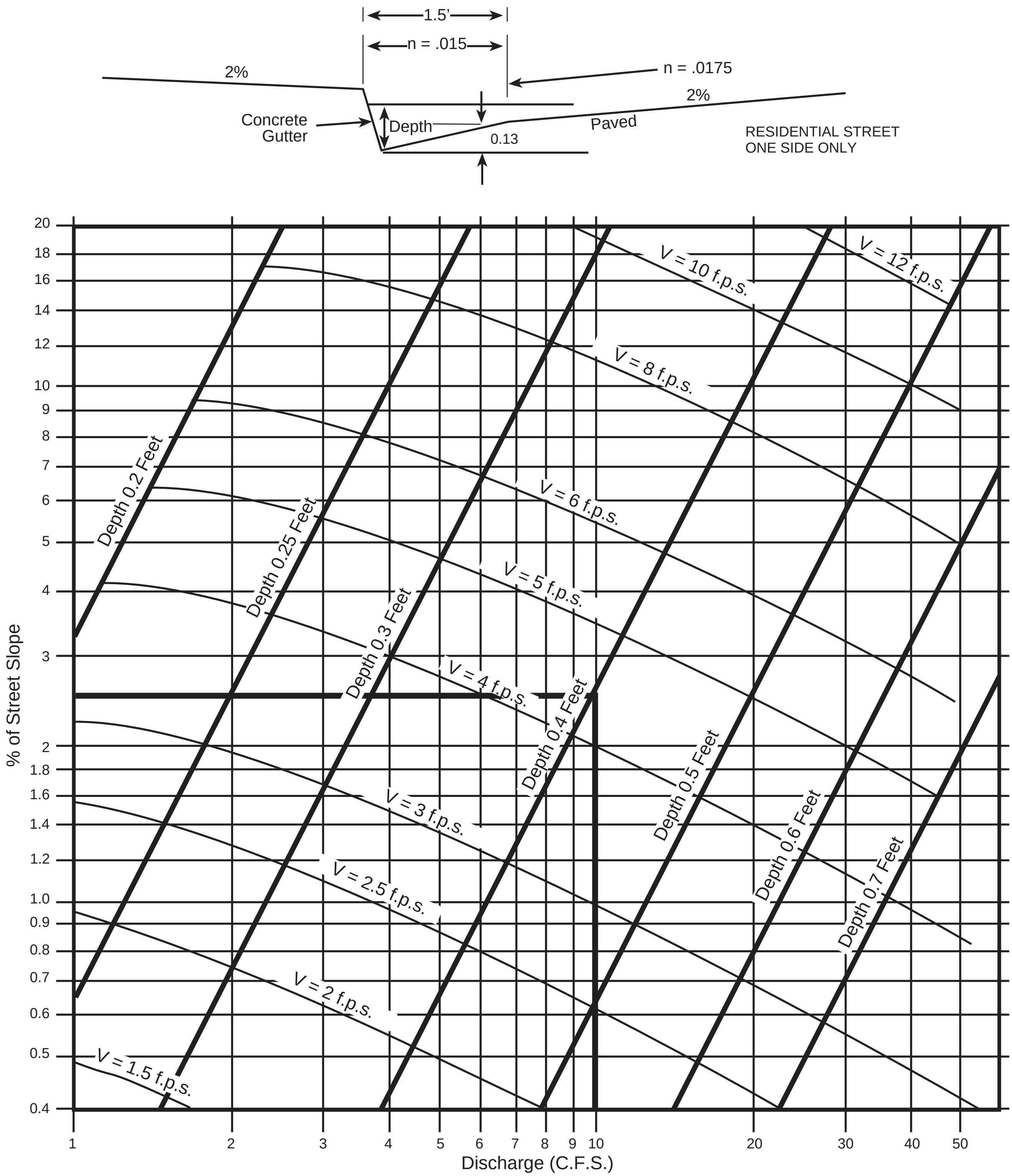
Nomograph for Determination of
Time of Concentration (Tc) or Travel Time (Tt) for Natural Watersheds



SOURCE: California Division of Highways (1941) and Kirpich (1940)

FIGURE 3-5

Computation of Effective Slope for Natural Watersheds



EXAMPLE:

Given: Q = 10 S = 2.5%

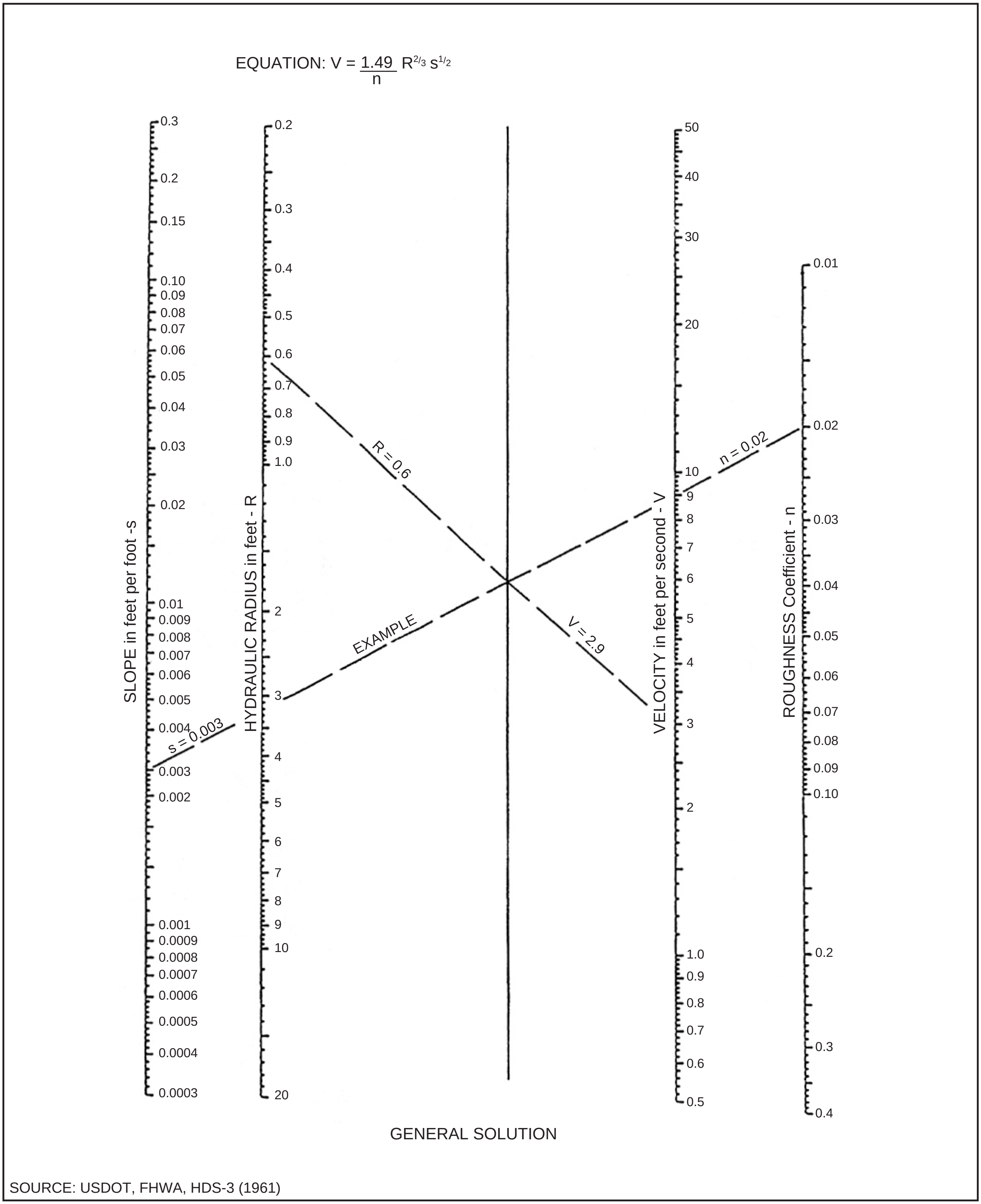
Chart gives: Depth = 0.4, Velocity = 4.4 f.p.s.

SOURCE: San Diego County Department of Special District Services Design Manual

Gutter and Roadway Discharge - Velocity Chart

FIGURE

3-6



Manning's Equation Nomograph

FIGURE 3-7

3.2 DEVELOPING INPUT DATA FOR THE RATIONAL METHOD

This section describes the development of the necessary data to perform RM calculations. Section 3.3 describes the RM calculation process. Input data for calculating peak flows and T_c's with the RM should be developed as follows:

1. On a topographic base map, outline the overall drainage area boundary, showing adjacent drains, existing and proposed drains, and overland flow paths.

2. Verify the accuracy of the drainage map in the field.

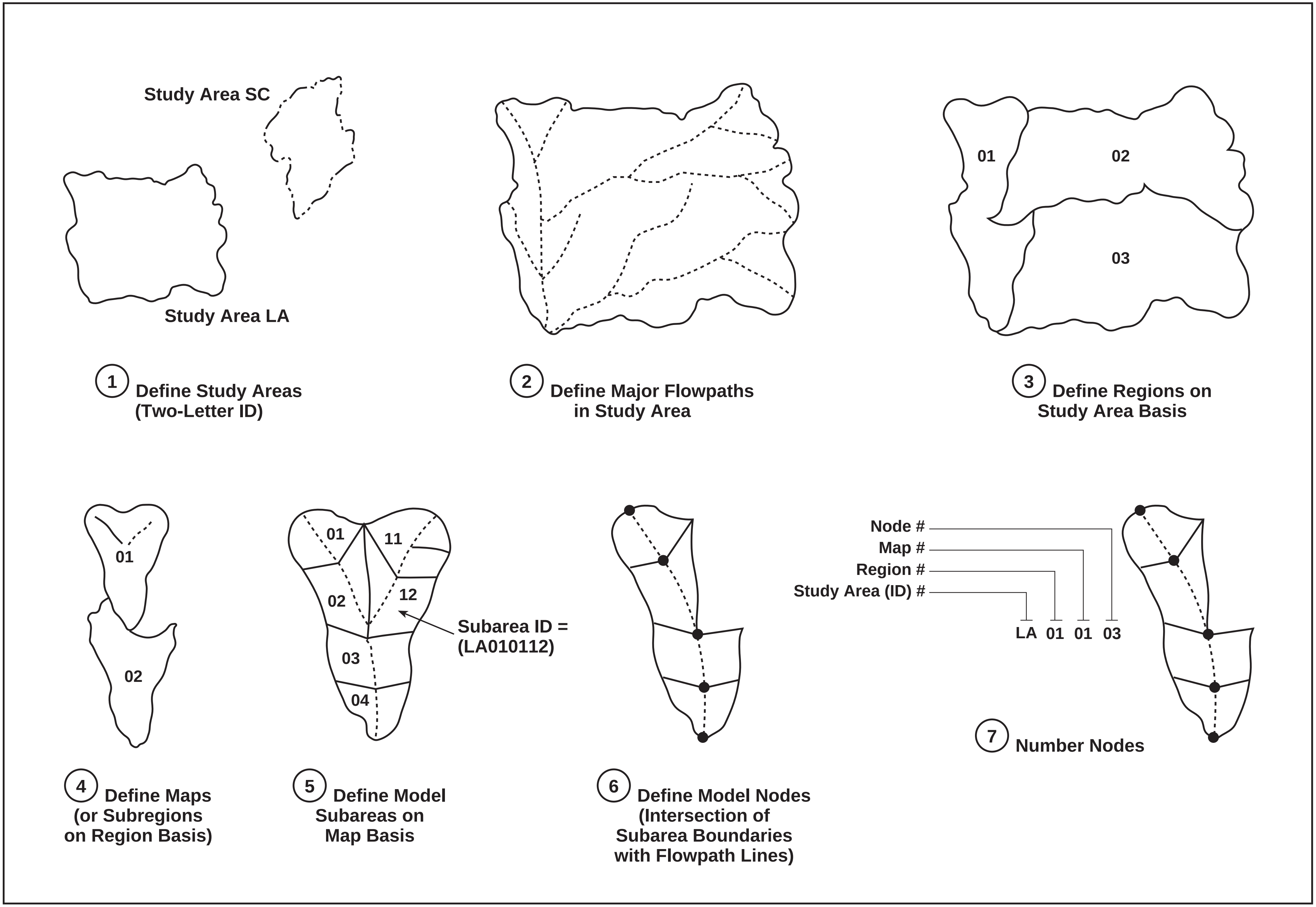
3. Divide the drainage area into subareas by locating significant points of interest. These divisions should be based on topography, soil type, and land use. Ensure that an appropriate first subarea is delineated. For natural areas, the first subarea flow path length should be less than or equal to 4,000 feet plus the overland flow length (Table 3-2). For developed areas, the initial subarea flow path length should be consistent with Table 3-2. The topography and slope within the initial subarea should be generally uniform.

4. Working from upstream to downstream, assign a number representing each subarea in the drainage system to each point of interest. Figure 3-8 provides guidelines for node numbers for geographic information system (GIS)-based studies.

5. Measure each subarea in the drainage area to determine its size in acres (A).

6. Determine the length and effective slope of the flow path in each subarea.

7. Identify the soil type for each subarea.



GIS/Hydrologic Model
Data Base Linkage Setup:
Nodes, Subareas, Links

FIGURE

3-8

8. Determine the runoff coefficient (C) for each subarea based on Table 3-1. If the subarea contains more than one type of development classification, use a proportionate average for C. In determining C for the subarea, use future land use taken from the applicable community plan, Multiple Species Conservation Plan, National Forest land use plan, etc.

9. Calculate the CA value for the subarea.

10. Calculate the Σ(CA) value(s) for the subareas upstream of the point(s) of interest.

11. Determine P_6 and P_{24} for the study using the isopluvial maps provided in Appendix B. If necessary, adjust the value for P_6 to be within 45% to 65% of the value for P_{24}.

See Section 3.3 for a description of the RM calculation process.

3.3 PERFORMING RATIONAL METHOD CALCULATIONS

This section describes the RM calculation process. Using the input data, calculation of peak flows and T_c's should be performed as follows:

1. Determine T_i for the first subarea. Use Table 3-2 or Figure 3-3 as discussed in Section 3.1.4. If the watershed is natural, the travel time to the downstream end of the first subarea can be added to T_i to obtain the $T_{c.}$ Refer to paragraph 3.1.4.2 (a).

2. Determine I for the subarea using Figure 3-1. If T_i was less than 5 minutes, use the 5 minute time to determine intensity for calculating the flow.

3. Calculate the peak discharge flow rate for the subarea, where $Q_p = \Sigma(CA)\ I$.
   In case that the downstream flow rate is less than the upstream flow rate, due to the long travel time that is not offset by the additional subarea runoff, use the upstream peak flow for design purposes until downstream flows increase again.

4. Estimate the T_t to the next point of interest.

5. Add the T_t to the previous T_c to obtain a new T_c.

6. Continue with step 2, above, until the final point of interest is reached.

Note: The MRM should be used to calculate the peak discharge when there is a junction from independent subareas into the drainage system.

3.4 MODIFIED RATIONAL METHOD (FOR JUNCTION ANALYSIS)

The purpose of this section is to describe the steps necessary to develop a hydrology report for a small watershed using the MRM. It is necessary to use the MRM if the watershed contains junctions of independent drainage systems. The process is based on the design manuals of the City/County of San Diego. The general process description for using this method, including an example of the application of this method, is described below.

The engineer should only use the MRM for drainage areas up to approximately 1 square mile in size. If the watershed will significantly exceed 1 square mile then the NRCS method described in Section 4 should be used. The engineer may choose to use either the RM or the MRM for calculations for up to an approximately 1-square-mile area and then transition the study to the NRCS method for additional downstream areas that exceed approximately 1 square mile. The transition process is described in Section 4.

3.4.1 Modified Rational Method General Process Description

The general process for the MRM differs from the RM only when a junction of independent drainage systems is reached. The peak Q, T_c, and I for each of the independent drainage systems at the point of the junction are calculated by the RM. The independent drainage systems are then combined using the MRM procedure described below. The peak Q, T_c, and I for each of the independent drainage systems at the point of the junction must be calculated prior to using the MRM procedure to combine the independent drainage systems, as these values will be used for the MRM calculations. After the independent drainage systems have been combined, RM calculations are continued to the next point of interest.

3.4.2 Procedure for Combining Independent Drainage Systems at a Junction

Calculate the peak Q, T_c, and I for each of the independent drainage systems at the point of the junction. These values will be used for the MRM calculations.

At the junction of two or more independent drainage systems, the respective peak flows are combined to obtain the maximum flow out of the junction at T_c. Based on the approximation that total runoff increases directly in proportion to time, a general equation may be written to determine the maximum Q and its corresponding T_c using the peak Q, T_c, and I for each of the independent drainage systems at the point immediately before the junction. The general equation requires that contributing Q's be numbered in order of increasing T_c.

Let Q_1, T_1, and I_1 correspond to the tributary area with the shortest T_c. Likewise, let Q_2, T_2, and I_2 correspond to the tributary area with the next longer T_c; Q_3, T_3, and I_3 correspond to the tributary area with the next longer T_c; and so on. When only two independent drainage systems are combined, leave Q_3, T_3, and I_3 out of the equation. Combine the independent drainage systems using the junction equation below:

Junction Equation: $T_1 < T_2 < T_3$

$$Q_{T1} = Q_1 + \frac{T_1}{T_2} Q_2 + \frac{T_1}{T_3} Q_3$$

$$Q_{T2} = Q_2 + \frac{I_2}{I_1} Q_1 + \frac{T_2}{T_3} Q_3$$

$$Q_{T3} = Q_3 + \frac{I_3}{I_1} Q_1 + \frac{I_3}{I_2} Q_2$$

Calculate Q_{T1}, Q_{T2}, and Q_{T3}. Select the largest Q and use the T_c associated with that Q for further calculations (see the three Notes for options). If the largest calculated Q's are equal (e.g., $Q_{T1} = Q_{T2} > Q_{T3}$), use the shorter of the T_c's associated with that Q.

This equation may be expanded for a junction of more than three independent drainage systems using the same concept. The concept is that when Q from a selected subarea (e.g., Q_2) is combined with Q from another subarea with a shorter T_c (e.g., Q_1), the Q from the subarea with the shorter T_c is reduced by the ratio of the I's (I_2/I_1); and when Q from a selected subarea (e.g., Q_2) is combined with Q from another subarea with a longer T_c (e.g., Q_3), the Q from the subarea with the longer T_c is reduced by the ratio of the T_c's (T_2/T_3).

Note #1: At a junction of two independent drainage systems that have the same T_c, the tributary flows may be added to obtain the Q_p.

$$Q_p = Q_1 + Q_2 \text{; when } T_1 = T_2\text{; and } T_c = T_1 = T_2$$

This can be verified by using the junction equation above. Let Q_3, T_3, and $I_3 = 0$. When T_1 and T_2 are the same, I_1 and I_2 are also the same, and T_1/T_2 and $I_2/I_1 = 1$. T_1/T_2 and I_2/I_1 are cancelled from the equations. At this point, $Q_{T1} = Q_{T2} = Q_1 + Q_2$.

Note #2: In the upstream part of a watershed, a conservative computation is acceptable. When the times of concentration (T_c's) are relatively close in magnitude (within 10%), use the shorter T_c for the intensity and the equation $Q = \Sigma(CA)I$.

Note #3: . An optional method of determining the T_c is to use the equation
$T_c = [(\Sigma\ (CA)7.44\ P_6)/Q]^{1.55}$

This equation is from $Q = \Sigma(CA)I = \Sigma(CA)(7.44\ P_6/T_c^{.645})$ and solving for T_c. The advantage in this option is that the T_c is consistent with the peak flow Q, and avoids inappropriate fluctuation in downstream flows in some cases.

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SECTION 4
THE SOIL CONSERVATION SERVICE – NRCS HYDROLOGIC METHOD

The Soil Conservation Service (SCS) (now called the Natural Resources Conservation Service [NRCS]) hydrologic method (NRCS hydrologic method) requires basic data similar to the RM: drainage area, a "runoff curve number" (CN) describing the proportion of rainfall that runs off, time to peak (T_p), the elapsed time from the beginning of unit effective rainfall to the peak flow for the point of concentration, and total rainfall (P). The NRCS approach, however, is more sophisticated in that it also considers the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during the course of a storm. Results of the NRCS approach are more detailed, in the form of a runoff hydrograph. Details of the methodology can be found in the NRCS National Engineering Handbook (NEH), Section 4 (NEH-4) (USDA, 1985). The NRCS hydrologic method should be used for study areas approximately 1 square mile and greater in size. The NRCS hydrologic method may be used for the entire study area, or the RM or MRM may be used for approximately 1 square mile of the study area and then transitioned to the NRCS hydrologic method using the procedure described in Section 4.4.

The NRCS method includes the following basic steps:

1. Delineation of the watershed on a map and determination of watershed physical characteristics including location of centroid, total length and length to centroid, soil type, and land use/land treatment,

2. Determination of time to peak, the elapsed time from the beginning of unit effective rainfall to the peak flow for the point of concentration, and/or lag time, the elapsed time from the beginning of unit effective rainfall to the instant that the summation hydrograph for the point of concentration reaches 50% of ultimate discharge,

3. Determination of frequency of design storm, and determination of total rainfall amount for the design storm and precipitation zone number (PZN) for the watershed location,

4. Preparation of incremental rainfall distribution,

5. Adjustment of incremental rainfall depths based on watershed area,

6. Determination of composite curve number (CN) for the watershed, which will represent different combinations of land use and soil type within the drainage area and describe the proportion of rainfall that runs off,

6. Adjustment of CN based on the PZN Condition,

7. Determination of excess rainfall amounts using the PZN adjusted composite CN for the watershed and the depth-area adjusted incremental rainfall distribution,

8. Using the dimensionless unit hydrograph approach, development of the hydrograph of direct runoff from the drainage area.

4.1 CONCEPTS AND EQUATIONS OF THE NRCS HYDROLOGIC METHOD

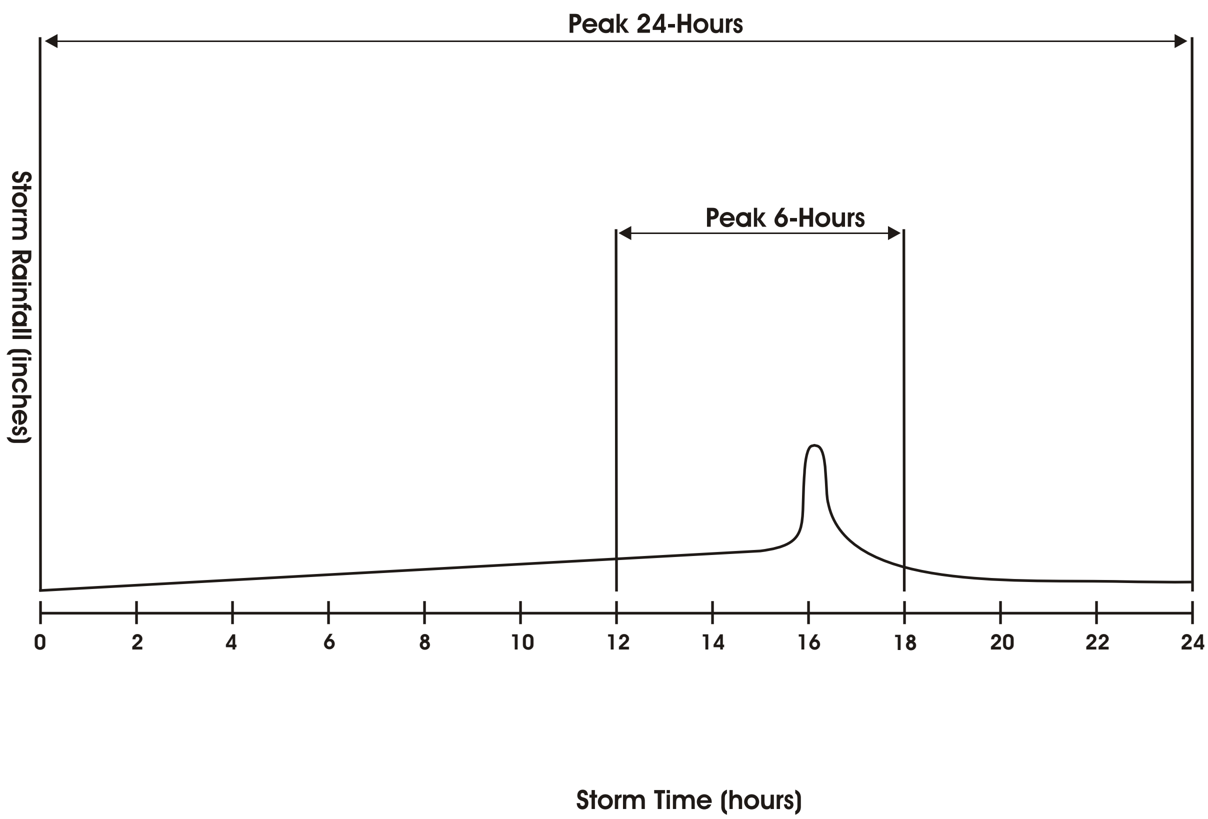
4.1.1 Rainfall Distribution

The hydrograph of storm runoff from a drainage area is based in part on the time distribution of rainfall during the storm. The variation in rainfall intensity that occurs from the beginning of the storm through the storm peak and the end of the storm is represented in the time distribution of rainfall. The time distribution of rainfall during a storm can be represented graphically as a hyetograph, a chart showing increments of average rainfall during successive units of time during a storm.

The rainfall distribution adopted for this manual is a nested storm pattern, based on the United States Army Corps of Engineers (USACE), Hydrologic Engineering Center (HEC) Training Document Number 15 (HEC TD-15), *Hydrologic Analysis of Ungaged Watersheds Using HEC-1* (USACE, 1982). A 24-hour nested storm shall be used for flood flow computations. The peak of the nested storm will occur at hour 16 of the 24-hour storm. The nested storm will be distributed about hour 16 of the 24-hour storm using a (2/3, 1/3) distribution. The nested storm pattern with (2/3, 1/3) distribution is shown in Figure 4-1. The nested storm is described below in Section 4.1.1.1, and the (2/3, 1/3) distribution is described below in Section 4.1.1.2.

The nested storm pattern with (2/3, 1/3) distribution supercedes the Type B and Type C rainfall distributions that were used in the 1993 edition of this manual for the westerly and easterly drainage areas of San Diego County, respectively. The nested storm pattern is appropriate for both the westerly and easterly drainage areas of San Diego County. A limitation of the Type B and Type C distributions was that each distribution was created for and applicable to the 6-hour and 24-hour durations only, and required separate analyses for to be prepared for each duration. In most cases, the 6-hour storm duration produced a higher peak flow rate, while the 24-hour storm duration generated a greater volume of runoff. Use of the nested storm pattern will eliminate the need for separate analyses for 6-hour and 24-hour storm durations. The Figures and Tables describing the 6-hour and 24-hour Type B and Type C rainfall distributions have been removed from this manual. The Figures and Tables describing these rainfall distributions can be obtained from the 1993 edition of this manual or from San Diego County DPWFCS if necessary for forensic study or other research.

In addition to the nested storm pattern with (2/3, 1/3) distribution, a rainfall depth-area adjustment based on the United States Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) Atlas 2 (NOAA Atlas 2), *Precipitation-Frequency Atlas of the Western United States, Volume IX, California* (NOAA, 1973) has been adopted with this manual. The rainfall depth-area adjustment based on NOAA Atlas 2 supersedes the Pacific Coastal Climate Area Reduction Ratio and the Arid and Semiarid



Time Distribution of Rainfall:
Nested Storm Pattern, with (2/3,1/3)
Distribution

FIGURE

4-1

Climate Area Reduction Factor given in the 1993 edition of this manual. The rainfall depth-area adjustment is discussed below in Section 4.1.1.3.

4.1.1.1 Nested Storm Pattern

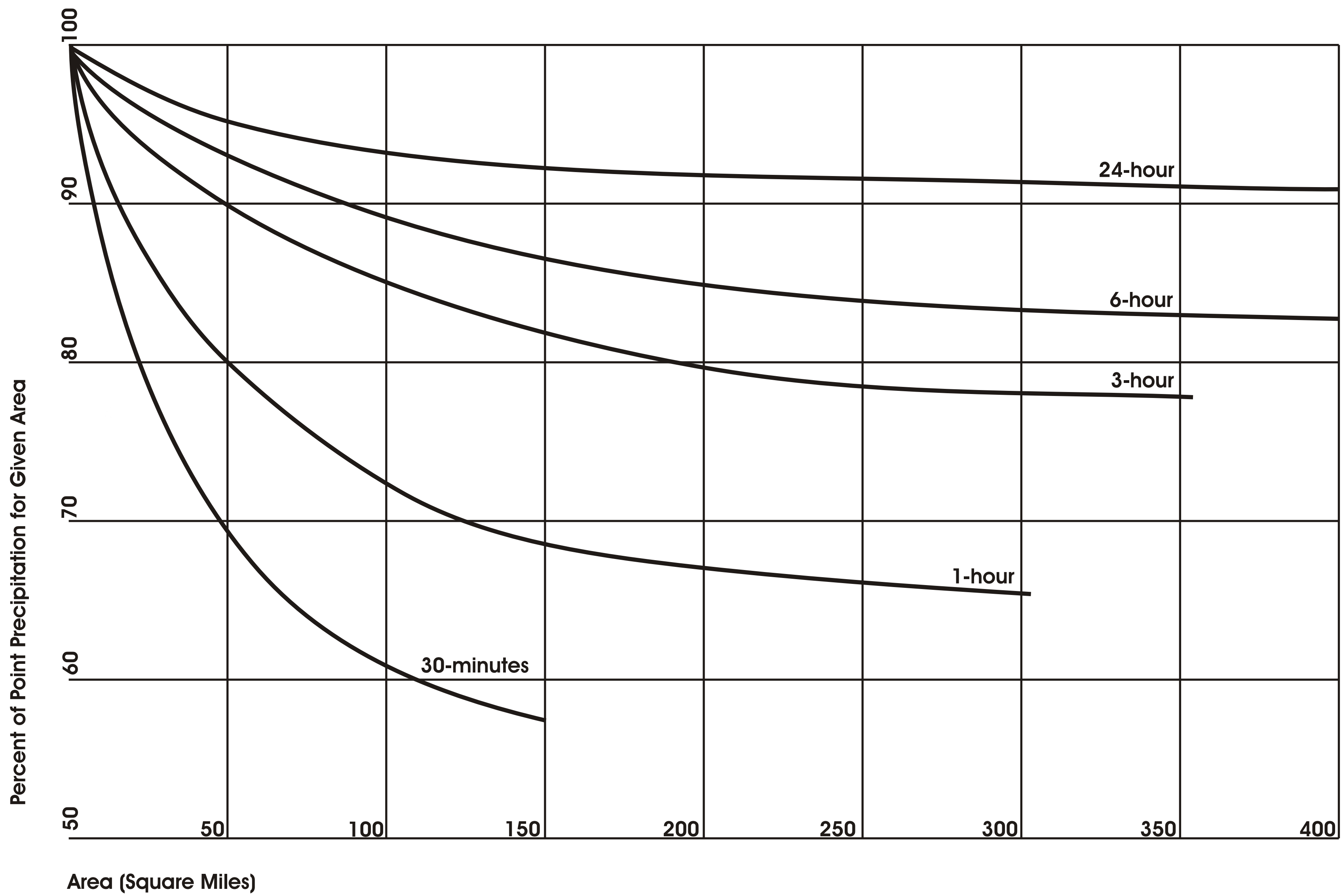
The nested storm pattern is a synthetic storm with the maximum rainfall intensities for a given storm frequency nested for duration between 5 minutes and 24 hours. The maximum 5 minutes of rainfall is nested within the maximum 10 minutes; the maximum 10 minutes is nested within the maximum 15 minutes; and so forth until the 24-hour storm pattern is developed. Figure 4-1 shows the nested storm pattern. This hypothetical storm pattern is referred to in HEC TD-15 as a "balanced storm", because of the consistent depth-frequency relation used for each peak duration interval. Use of a balanced storm permits the construction and arrangement of a storm event such that an average rainfall intensity of a specified frequency is provided for all durations – including one that matches the time-response characteristics of the particular watershed being analyzed. Every watershed is sensitive to a particular duration of rainfall that will produce the peak discharge, usually a duration approximating the time of concentration of the watershed. A nested duration design storm, analogous to a "balanced hydrograph", ensures that each watershed will receive the design frequency depth of rainfall for its critical duration. Durations longer or shorter than the critical duration have little effect on peak discharge, although longer durations have considerable effect on total volume of runoff. Section 4.3.2 provides further guidance for creation of the rainfall distribution.

4.1.1.2 Shape of Rainfall Distribution Hyetograph

For preparation of the hyetograph (a chart showing increments of average rainfall during successive units of time during a storm) for a hydrologic study, increments of average rainfall shall be calculated using the methods described in Section 4.3.2, and a (2/3, 1/3) rainfall distribution nested about hour 16 of the 24-hour storm shall be used to distribute the rainfall increments. HEC TD-15 suggests a (1/2, 1/2) distribution in which the peak rainfall intensity is placed at the center of the storm; however, other distributions are not ruled out. A sensitivity analysis was performed for Orange County, California watersheds (Hromadka, 1987) to determine the effect of these two storm distributions on peak flow rates. It was concluded that a reasonable variation of the design storm pattern shape would have a negligible effect on the modeling output of peak flow rate. However, the distribution of runoff volume varies within the runoff hydrograph depending upon the design storm pattern rainfall distribution. In reservoir or detention basin design the impacts on total storage volume required would be significant. This is the reason the (2/3, 1/3) distribution was adopted for this manual. Figure 4-1 shows the (2/3, 1/3) distribution nested about hour 16 of the 24-hour storm.

4.1.1.3 Rainfall Depth-Area Adjustment

The rainfall values on the isopluvial maps provided in Appendix B and the rainfall values that must be computed to create the ordinates of the nested storm pattern hyetograph represent point rainfall. However, the average rainfall over a given area will be less than the maximum point value in the area. NOAA Atlas 2 establishes a rainfall depth-area adjustment that may be applied to the point rainfall values. Figure 4-2 gives the adjustment to the point rainfall value for various rainfall durations as a function of watershed area. Table 4-1 provides the depth-area adjustment data points that are built in to the San Diego Unit Hydrograph (SDUH) Peak Discharge Program that is provided with this manual (the SDUH Peak Discharge Program is discussed in Section 4.3). These data points were obtained from Figure 4-2. For consistency between studies, it is recommended that the depth-area adjustment factors be interpolated from Table 4-1. The depth-area adjustment may be applied for watershed approximately 1 square mile or greater in size. The depth-area adjustment should be applied to the incremental rainfall amounts prior to arranging the incremental rainfall amounts in the (2/3, 1/3) distribution.



Source: NOAA Atlas 2 Precipitation-Frequency Atlas of the Western United States Volume IX-California, 1973

FIGURE

4-2

Rainfall Depth-Area Adjustment Curves

Table 4-1
RAINFALL DEPTH-AREA ADJUSTMENT DATA POINTS

Watershed Area (square miles)	Rainfall Depth-Area Adjustment for Duration				
	30-Minute	1-Hour	3-Hour	6-Hour	24-Hour
0	1.000	1.000	1.000	1.000	1.000
5	0.942	0.970	0.980	0.985	0.990
10	0.900	0.947	0.970	0.980	0.985
20	0.834	0.900	0.952	0.963	0.975
30	0.768	0.858	0.932	0.950	0.964
40	0.730	0.830	0.915	0.940	0.958
50	0.692	0.800	0.900	0.928	0.952
60	0.663	0.778	0.883	0.920	0.948
70	0.645	0.760	0.872	0.912	0.945
80	0.630	0.746	0.862	0.904	0.942
90	0.620	0.735	0.853	0.896	0.938
100	0.610	0.722	0.845	0.890	0.935
125	0.588	0.700	0.830	0.878	0.930
150	0.572	0.685	0.818	0.865	0.925
175	0.572	0.672	0.808	0.858	0.922
200	0.572	0.666	0.798	0.851	0.918
225	0.572	0.660	0.790	0.845	0.915
250	0.572	0.655	0.787	0.842	0.914
300	0.572	0.652	0.782	0.838	0.912
350	0.572	0.652	0.780	0.830	0.910
400	0.572	0.652	0.780	0.828	0.908

4.1.2 Runoff Curve Number

The hydrograph of storm runoff from a drainage area is also based in part on the physical characteristics of the watershed. The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types, and land slope. The NRCS method uses a combination of soil conditions and land uses (ground cover) and land treatment (generally agricultural practices) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CNs), indicate the runoff potential of an area. The higher the CN, the higher the runoff potential. The CN does not account for land slope. However, in the NRCS hydrologic method land slope is accounted for in the determination of watershed lag time (see Section 4.1.3).

The CN values in Table 4-2 are suitable for preparing hydrographs in accordance with the methods shown in Chapters 10 and 16 of NEH-4 and summarized in Section 4.2 of this manual. The CN values are based on hydrologic soil group and land use/land treatment. Tables 4-3, 4-4, and 4-5 provide descriptions of some of the terms used in Table 4-2, including vegetative condition and cover density. See the glossary for descriptions of land uses and hydrologic conditions listed in Tables 4-2 through 4-5. When a drainage area has more than one land use, a composite CN can be calculated and used in the analysis (see Section 4.2.3). It should be noted that when composite CNs are used, the analysis does not take into account the location of the specific land uses but treats the drainage area as a uniform land use represented by the composite CN.

Note: The CN values in Table 4-2 are unadjusted for PZN Condition. These are suitable where the PZN adjustment factor = 2.0, which represents the average PZN Condition. The PZN Condition and PZN adjustment factor are discussed in Section 4.1.2.4.

Table 4-2
RUNOFF CURVE NUMBERS[1] FOR PZN CONDITION = 2.0

Cover Description	Cover Treatment or Practice[2]	Hydrologic Condition[3]	Average Percent Impervious Area[4]	Curve Numbers for Hydrologic Soil Groups: A	B	C	D
Developing urban areas and newly graded areas (pervious areas only, no vegetation)				77	86	91	94
Impervious areas: Paved parking lots, roofs, and driveways (excluding right-of-way)				98	98	98	98
Residential districts by average lot size:[4]							
1/8 acre or less (town houses)			65%	77	85	90	92
1/4 acre			38%	61	75	83	87
1/3 acre			30%	57	72	81	86
1/2 acre			25%	54	70	80	85
1 acre			20%	51	68	79	84
2 acres			12%	46	65	77	82
Streets and roads	Paved; curbs and storm drains (excluding right-of-way)			98	98	98	98
	Paved; open ditches (including right-of-way)			83	89	92	93
	Gravel (including right-of-way)			76	85	89	91
	Hard surface (including right-of-way)			74	84	90	92
	Dirt (including right-of-way)			72	82	87	89
Urban districts[4]	Commercial and business		85%	89	92	94	95
	Industrial		72%	81	88	91	93
Western desert urban areas:							
Natural desert landscaping (pervious areas only)[5]				63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)				96	96	96	96

Table 4-2 (Continued)
RUNOFF CURVE NUMBERS[1] FOR PZN CONDITION = 2.0

Cover Description	Cover Treatment or Practice[2]	Hydrologic Condition[3]	Average Percent Impervious Area[4]	Curve Numbers for Hydrologic Soil Groups: A	B	C	D
Close-seeded legumes or rotated pasture	Straight row	Poor		66	77	85	89
		Good		58	72	81	85
	Contoured	Poor		64	75	83	85
		Good		55	69	78	83
	Contoured and terraced	Poor		63	73	80	83
		Good		51	67	76	80
Cultivated land	Without conservation treatment			72	81	88	91
	With conservation treatment			62	71	78	81
Fallow	Bare soil			77	86	91	94
	Crop residue cover	Poor		76	85	90	92
		Good		74	83	88	90
Farmsteads (buildings, lanes, driveways, and surrounding lots)				59	74	82	86
Irrigated pasture		Poor		58	74	83	87
		Fair		44	65	77	82
		Good		33	58	72	79
Orchards (deciduous)		(see glossary description)					
Orchards (evergreen)		Poor		57	73	82	86
		Fair		44	65	77	82
		Good		33	58	72	79
Row crops	Straight row	Poor		72	81	88	91
		Good		67	78	85	89
	Contoured	Poor		70	79	84	88
		Good		65	75	82	86

Table 4-2 (Continued)
RUNOFF CURVE NUMBERS[1] FOR PZN CONDITION = 2.0

Cover Description	Cover Treatment or Practice[2]	Hydrologic Condition[3]	Average Percent Impervious Area[4]	Curve Numbers for Hydrologic Soil Groups: A	B	C	D
Small grain	Straight row	Poor		65	76	84	88
		Good		63	75	83	87
	Contoured	Poor		63	74	82	85
		Good		61	73	81	84
Vineyards[6]	Disked			76	85	90	92
	Annual grass or legume cover	Poor		65	78	85	89
		Fair		50	69	79	84
		Good		38	61	74	80
Annual grass (Dryland pasture)		Poor		67	78	86	89
		Fair		50	69	79	84
		Good		38	61	74	80
Barren				78	86	91	93
Meadow		Poor		63	77	85	88
		Fair		51	70	80	84
		Good		30	58	72	78
Open space (lawns, parks, golf courses, cemeteries, etc.)[7]	Grass cover <50%	Poor		68	79	86	89
	Grass cover 50% to 75%	Fair		49	69	79	84
	Grass cover >75%	Good		39	61	74	80
Pasture or range land		Poor		68	79	86	89
		Fair		49	69	79	84
		Good		39	61	74	80
Perennial grass		Poor		67	79	86	89
		Fair		50	69	79	84
		Good		38	61	74	80

Table 4-2 (Continued)
RUNOFF CURVE NUMBERS[1] FOR PZN CONDITION = 2.0

Cover Description	Cover Treatment or Practice[2]	Hydrologic Condition[3]	Average Percent Impervious Area[4]	Curve Numbers for Hydrologic Soil Groups: A	B	C	D
Turf[8]		Poor		58	74	83	87
		Fair		44	65	77	82
		Good		33	58	72	79
Water surfaces (during floods)				97	98	99	99
Broadleaf chaparral		Poor		53	70	80	85
		Fair		40	63	75	81
		Good		31	57	71	78
Desert shrub–major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus		Poor		63	77	85	88
		Fair		55	72	81	86
		Good		49	68	79	84
Herbaceous–mixture of grass, weeds, and low-growing brush, with brush the minor element		Poor		[9]	80	87	93
		Fair		[9]	71	81	89
		Good		[9]	62	74	85
Narrowleaf chaparral		Poor		71	82	88	91
		Fair		55	72	81	86
Oak-aspen–mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush		Poor		[9]	66	74	79
		Fair		[9]	48	57	63
		Good		[9]	30	41	48
Open brush		Poor		62	76	84	88
		Fair		46	66	77	83
		Good		41	63	75	81

Table 4-2 (Continued)
RUNOFF CURVE NUMBERS[1] FOR PZN CONDITION = 2.0

Cover Description	Cover Treatment or Practice[2]	Hydrologic Condition[3]	Average Percent Impervious Area[4]	Curve Numbers for Hydrologic Soil Groups: A	B	C	D
Pinyon-juniper–pinyon, juniper, or both; grass understory		Poor		[9]	75	85	89
		Fair		[9]	58	73	80
		Good		[9]	41	61	71
Sagebrush with grass understory		Poor		[9]	67	80	85
		Fair		[9]	51	63	70
		Good		[9]	35	47	55
Wood or forest land		Thin stand, poor cover		45	66	77	83
		Good cover		25	55	70	77
Woods (woodland)		Poor		45	66	77	83
		Fair		36	60	73	79
		Good		28	55	70	77
Woodland-grass combination		Poor		57	73	82	86
		Fair		44	65	77	82
		Good		33	58	72	79

1 Average runoff condition, and $I_a = 0.2S$.
2 Hydrologic practices described as "straight row" and "contoured" are defined in the glossary.
3 For definition of hydrologic condition, see Tables 4-3, 4-4, and 4-5.
4 The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. If the impervious area is not directly connected, the NRCS method has an adjustment to reduce the effect.
5 Composite CNs for natural desert landscaping should be computed based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.
6 See glossary.
7 CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.
8 Includes lawns, cemeteries, golf courses and parks with ground cover of mowed and irrigated perennial grass.
9 CNs for Group A have not been developed.

Table 4-3

CLASSIFICATION OF NATIVE PASTURE OR RANGE

Vegetative Condition	Hydrologic Condition
Heavily grazed. Has no mulch or has plant cover on less than 50% of the area.	Poor
Not heavily grazed. Has plant cover on 50% to 75% of the area.	Fair
Lightly grazed. Has plant cover on more than 75% of the area.	Good

Table 4-4

AIR-DRY WEIGHT CLASSIFICATION OF NATIVE PASTURE OR RANGE

	Plant and litter air-dry weight (tons per acre):		
Cover density	Less than 0.5	0.5 to 1.5	More than 1.5
Less than 50%	Poor	Poor+	Fair
50% to 75%	Poor+	Fair	Fair+
More than 75%	Fair	Fair+	Good

Table 4-5

CLASSIFICATION OF WOODS

Vegetative Condition	Hydrologic Condition
Heavily grazed or regularly burned. Litter, small trees, and brush are destroyed.	Poor
Grazed but not burned. There may be some litter but these woods are not protected.	Fair
Protected from grazing. Litter and shrubs cover the soil.	Good

4.1.2.1 Hydrologic Soil Group

Soil properties influence the relationship between rainfall and runoff since soils have differing rates of infiltration. Based on infiltration rates, the NRCS has divided soils into four hydrologic soil groups.

Group A
Soils have high infiltration rate when thoroughly wetted; chiefly deep, well-drained to excessively drained sand, gravel, or both. Rate of water transmission is high; thus runoff potential is low.

Group B
Soils have moderate infiltration rate when thoroughly wetted; chiefly soils that are moderately deep to deep, moderately well drained to well drained, and moderately coarse textured. Rate of water transmission is moderate.

Group C
Soils have slow infiltration rate when thoroughly wetted; chiefly soils that have a layer impeding downward movement of water, or moderately fine to fine textured soils that have a slow infiltration rate. Rate of water transmission is slow.

Group D
Soils have very slow infiltration rate when thoroughly wetted; chiefly clays that have a high shrink-swell potential, soils that have a high permanent water table, soils that have a claypan or clay layer at or near the surface, or soils that are shallow over nearly impervious material. Rate of water transmission is very slow.

A list of soils throughout San Diego County and their hydrologic classification is located on the map in Appendix A. Soil Survey maps can be obtained from local NRCS offices for use in estimating soil type. The NRCS maps are also available at the County of San Diego DPWFCS. Consideration should be given to the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction or if grading will mix the surface and subsurface soils, appropriate changes should be made in the soil group selected.

4.1.2.2 Land Use/Land Treatment (Ground Cover)

Ground cover is used in combination with soil type to determine CN. Ground cover includes both land use and land treatment. Land use is defined as the type of watershed cover and includes every kind of vegetation, litter, mulch, and fallow as well as nonagricultural uses such as water surfaces (lakes, swamps, etc.) and impervious surfaces (roads, roofs, etc.). Land treatment applies mainly to agricultural land uses and it includes mechanical practices such as contouring or terracing and management practices such as grazing control or rotation of crops.

The NRCS has developed ground cover maps for San Diego County outlining vegetative and man-made cover. Ground cover maps can be obtained from local NRCS offices. The NRCS maps are also available at the County of San Diego DPWFCS. These maps may be used to determine the ground cover in the study area. Information on land use and treatment may also be obtained either by observation or by measurement of plant and litter density on sample areas. The CN values to be used for engineering design should correspond to the land use during the season for which maximum runoff is expected.

4.1.2.3 Urban Modifications

The urbanization of an area influences the relationship between rainfall and runoff by changing the percentage of impervious ground cover and changing the travel path of the runoff by concentrating flow in ditches, swales, gutters, channels, or pipes. The percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system must be considered in computing CN for urban areas. Specifically, whether the impervious areas connect directly to the drainage system or outlet onto lawns or other pervious areas where infiltration can occur prior to entering the storm drain system must be considered.

The CN values given in Table 4-2 for urban land uses are based on directly connected impervious areas and specific assumed percentages of impervious area. An impervious area is considered directly connected if runoff from it flows directly into the drainage system. It is also considered directly connected if runoff from it occurs as concentrated shallow flow that runs over pervious areas (such as flow in a swale) and then into a drainage system. The CN values given in Table 4-2 were developed on the assumptions that:

(a) pervious urban areas are equivalent to pasture in good hydrologic condition, and

(b) impervious areas have a CN of 98 and are directly connected to the drainage system.

It is possible that CN values from urban areas could be reduced by not directly connecting impervious surfaces to the drainage system, but allowing runoff to flow as sheet flow over significant pervious areas. Sections 4.2.3.1 and 4.2.3.2 describe the method for adjusting CN values for land uses where impervious areas are not directly connected.

4.1.2.4 PZN Condition

The isopluvial lines representing total 6-hour and 24-hour rainfall depths that are provided in Appendix B are based on a regression analysis procedure developed from plotting the location of precipitation gauges on topography maps and developing regression equations that relate parameters of elevation and distance from the ocean to the precipitation lines. Similarly, the precipitation zone number (PZN) map provided in Appendix C was also developed to reflect the orographic effects in San Diego County. The basic categories of coast, foothill, mountain, and desert were selected as precipitation zones 1.0, 2.0, 3.0, and 4.0, respectively, because the NWS used these terms in forecasting rainfall amounts and because the county is divided into these climatic zones for agricultural purposes. The lines between precipitation zones were adjusted to conform more closely to the isopluvial lines of equal precipitation. PZNs are read from the PZN map provided in Appendix C.

The hydrograph of storm runoff from a drainage area is based in part on the degree of watershed wetness at the beginning of the storm. The index of watershed wetness used with the runoff estimation method is PZN Condition. The PZN adjustment factor is a factor used to adjust the runoff curve number (Section 4.1.2) for the watershed to the appropriate PZN Condition. Three levels of PZN Condition are used (the PZN adjustment factors correspond to these PZN Conditions):

> PZN Condition = 1.0. Lowest runoff potential. The watershed soils are dry enough for satisfactory plowing or cultivation to take place.
>
> PZN Condition = 2.0. The average condition.
>
> PZN Condition = 3.0. Highest runoff potential. The watershed is practically saturated from antecedent rains.

The CNs given in Table 4-2 are for PZN Condition = 2.0 (PZN adjustment factor = 2.0). CNs must be adjusted for PZN Condition based on the storm frequency and the location of the watershed within the county. The location of the watershed within the county is represented by the PZN from the map provided in Appendix C. The PZN adjustment factors for combinations of PZN and storm frequency are given in Table 4-6. The PZN adjustment factor can also be approximated by multiplying the previous 5 days of accumulated rainfall by 1.4. The maximum PZN adjustment factor is 3.0, representing PZN Condition 3.0, a saturated condition. Since the PZN adjustment factor is based on the previous 5-day precipitation amounts before major storms, a statistical analysis of these data provided the values listed in Table 4-6. Adjustment from PZN Condition 2.0 to other PZN Conditions can be accomplished by using the information shown in Tables 4-6 and 4-10 (see Section 4.2.4 for Table 4-10).

The adjustment for PZN Condition may be made to the composite CN for the watershed. It is not necessary to make the PZN Condition adjustment to each of the CNs for the different combinations of ground cover and soil group within the watershed before calculating the composite CN.

Table 4-6

PZN ADJUSTMENT FACTORS FOR FLOW COMPUTATIONS
(San Diego County)

Storm Frequency	Coast (PZN = 1.0)	Foothills (PZN = 2.0)	Mountains (PZN = 3.0)	Desert (PZN = 4.0)
Less than 35-year return period	1.5	2.5	2.0	1.5
Greater than or equal to 35-year return period	2.0	3.0	3.0	2.0

Notes: PZN is the precipitation zone number (see Map, Appendix C). The PZN adjustment factor represents the PZN Condition that the CN for the watershed should be adjusted to.

4.1.3 Rainfall-Runoff Relationship

A relationship between accumulated rainfall and accumulated runoff was derived by NRCS from experimental plots for numerous soils and vegetative cover conditions. The following NRCS runoff equation is used to estimate direct runoff from 24-hour or 6-hour storm rainfall. The equation is:

$$Q_a = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{(Eq. 4-1)}$$

where: Q_a = accumulated direct runoff (in)
P = accumulated rainfall (potential maximum runoff) (in)
I_a = initial abstraction including surface storage, interception, evaporation, and infiltration prior to runoff (in)
S = potential maximum soil retention (in)

S is based on the CN for the drainage area. The equation is:

$$S = 1000/CN - 10 \qquad \text{(Eq. 4-2)}$$

An empirical relationship used in the NRCS method for estimating I_a is:

$$I_a = 0.2S \qquad \text{(Eq. 4-3)}$$

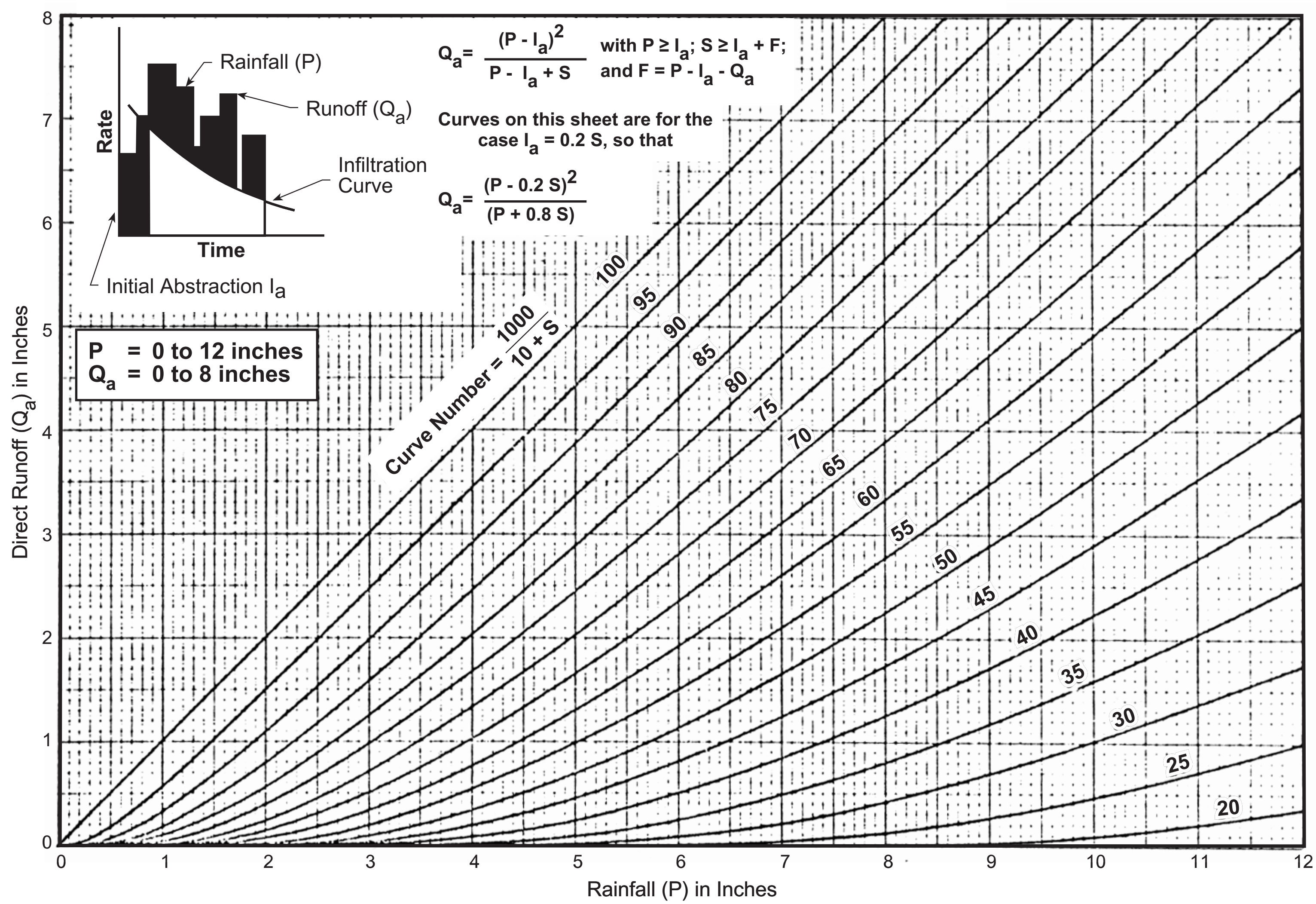
This is an average value that may be adjusted for flatter areas with more depressions if calibration data exists to substantiate the adjustment.

Substituting 0.2S for I_a in equation 4-1, the equation becomes:

$$Q_a = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad \text{(Eq. 4-4)}$$

Equation 4-4 is subject to the limitation $P \geq 0.2S$.

Figure 4-3 shows a graphical solution of this equation. For example, 4.1 inches of direct runoff would result if 5.8 inches of rainfall occurred on a watershed with a CN of 85.



SOURCE: TR-55, Second Ed., June 1986

NRCS Solution of the Runoff Equation

FIGURE

4-3

4.1.4 Unit Hydrograph

The hydrograph of outflow from a drainage area is the sum of the elemental hydrographs from all the subareas, modified by the effects of transit time through the drainage area and storage in the stream channels. The NRCS method for estimating peak discharge and hydrographs is based on the unit hydrograph concept. The following discussion is taken from Chapter 16 of NEH-4.

To generate the peak discharge estimates and runoff hydrograph using the NRCS method, a rainfall distribution is used to estimate the variation in rainfall during the design storm event. Rainfall is divided into small time increments. The runoff hydrograph is then generated by developing incremental unit hydrographs for the different incremental rainfall time periods. The general procedure is to calculate the accumulated runoff (Q_a) using the NRCS derived equations for estimating Q_a presented below. Incremental values of Q_a are then obtained for each successive time period. These values are multiplied by the unit hydrograph peak to produce a peak value for the incremental hydrograph. The peak discharge values for incremental hydrographs provide the value for the ordinate. If the hand calculation method is used, the base of each triangle and the point of time at which the peak occurs are obtained by calculating the time from the beginning of runoff to the peak of the runoff, and the time from the peak of the runoff to the point where there is zero runoff. The result is a series of storm increments that when added together provide the runoff hydrograph.

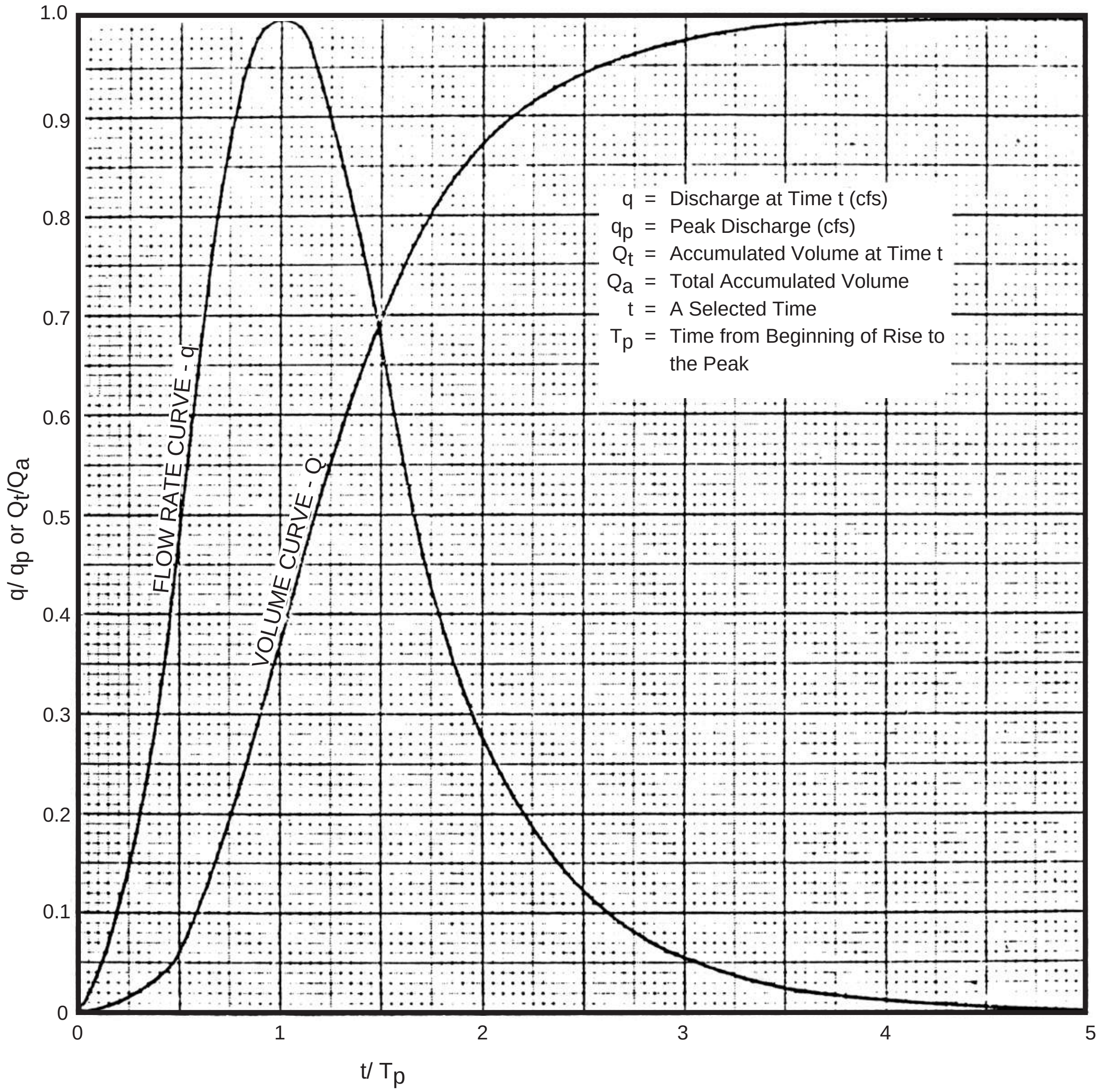
Since the physical characteristics of the drainage area, including shape, size, and slope, are constant from one storm to the next, the unit hydrograph approach assumes that there is considerable similarity in the shape of hydrographs from storms of similar rainfall characteristics (duration and intensity). Thus the unit hydrograph is a typical hydrograph for the drainage area with a runoff volume under the hydrograph equal to 1 inch from a storm of specified duration. For a storm of the same duration but with a different amount of runoff, the hydrograph of direct runoff can be expected to have the same time base as the unit hydrograph and ordinates of flow proportional to the incremental runoff volume.

Thus a storm that produces 2 inches of runoff would have a hydrograph with ordinates of flow equal to twice the ordinates of flow of the unit hydrograph. With 0.5 inches of runoff, the ordinates of flow of the hydrograph would be one-half of the ordinates of flow of the unit hydrograph.

The fundamental principles of invariance and superposition make the unit hydrograph an extremely flexible tool for developing synthetic hydrographs. The hydrograph of surface runoff from a watershed due to a given pattern of rainfall is invariable, and the hydrograph resulting from a given pattern of excess rainfall can be built up by superimposing the unit hydrograph due to the separate amounts of excess rainfall occurring in each unit period. This includes the principle of proportionality by which the ordinates of the hydrograph are proportional to the volume of excess rainfall.

The unit time or "unit hydrograph duration" is the optimum duration for occurrence of excess rainfall. In general, this unit time is approximately 20% of the time interval between the beginning of runoff from a short high-intensity storm and the peak discharge of the corresponding runoff.

The "storm duration" is the actual duration of the excess rainfall. The duration varies with actual storms. The dimensionless unit hydrograph used by NRCS (Figure 4-4) was developed by Victor Mockus. It was derived from a large number of natural unit hydrographs from watersheds varying widely in size and geographical locations. This dimensionless curvilinear hydrograph, also shown in Table 4-7, has its ordinate values expressed in a dimensionless ratio q/q_p or Q_t/Q_a and its abscissa values as t/T_p. This unit hydrograph has a point of inflection approximately 1.70 times the time to peak and the time-to-peak 0.2 of the time of base (T_b).



Dimensionless Unit Hydrograph and Volume Curve

FIGURE

4-4

Table 4-7

RATIOS FOR THE NATURAL RESOURCES CONSERVATION SERVICE DIMENSIONLESS UNIT HYDROGRAPH*

Values for (t/T_p) Increments ≈ 0.1			Values for (t/T_p) Increments = 0.2	
Time Ratios (t/T_p)	Discharge Ratios (q/q_p)	Mass Curve Ratios (Q_t/Q_a)	Time Ratios (t/T_p)	Discharge Ratios (q/q_p)
0	0.000	0.000	0	0.000
0.1	0.030	0.001	0.2	0.100
0.2	0.100	0.006	0.4	0.310
0.3	0.190	0.017	0.6	0.660
0.4	0.310	0.035	0.8	0.930
0.5	0.470	0.065	1.0	1.000
0.6	0.660	0.107	1.2	0.930
0.7	0.820	0.163	1.4	0.780
0.8	0.930	0.228	1.6	0.560
0.9	0.990	0.300	1.8	0.390
1.0	1.000	0.375	2.0	0.280
1.1	0.990	0.450	2.2	0.207
1.2	0.930	0.522	2.4	0.147
1.3	0.860	0.589	2.6	0.107
1.4	0.780	0.650	2.8	0.077
1.5	0.680	0.705	3.0	0.055
1.6	0.560	0.751	3.2	0.040
1.7	0.460	0.790	3.4	0.029
1.8	0.390	0.822	3.6	0.021
1.9	0.330	0.849	3.8	0.015
2.0	0.280	0.871	4.0	0.011
2.2	0.207	0.908	4.2	0.010
2.4	0.147	0.934	4.4	0.007
2.6	0.107	0.953	4.6	0.003
2.8	0.077	0.967	4.8	0.001
3.0	0.055	0.977	5.0	0.000
3.2	0.040	0.984		
3.4	0.029	0.989		Total = 6.67
3.6	0.021	0.993		
3.8	0.015	0.995		
4.0	0.011	0.997		
4.5	0.005	0.999		
5.0	0.000	1.000		

*Runoff = 1 inch
Source: U.S. Department of Commerce, NEH4, 1985.

Elements of a Unit Hydrograph

The dimensionless curvilinear unit hydrograph (Figure 4-4) has 37.5% of the total volume in the rising side, which is represented by one unit of time and one unit of discharge. The dimensionless unit hydrograph also can be represented by an equivalent triangular hydrograph having the same units of time and discharge, thus having the same percent of volume in the rising side of the triangle (Figure 4-5).

This allows the base of the triangle to be solved in relation to the T_p using the geometry of triangles. Solving for the base length of the triangle, if one unit of time T_p equals 0.375 of volume:

$$T_b = \frac{1.00}{0.375} = 2.67 \text{ units of time,}$$

$$T_r = T_b - T_p = 1.67 \text{ units of time or } 1.67\ T_p$$

where: T_b = time of base
T_p = time to peak
T_r = recession time

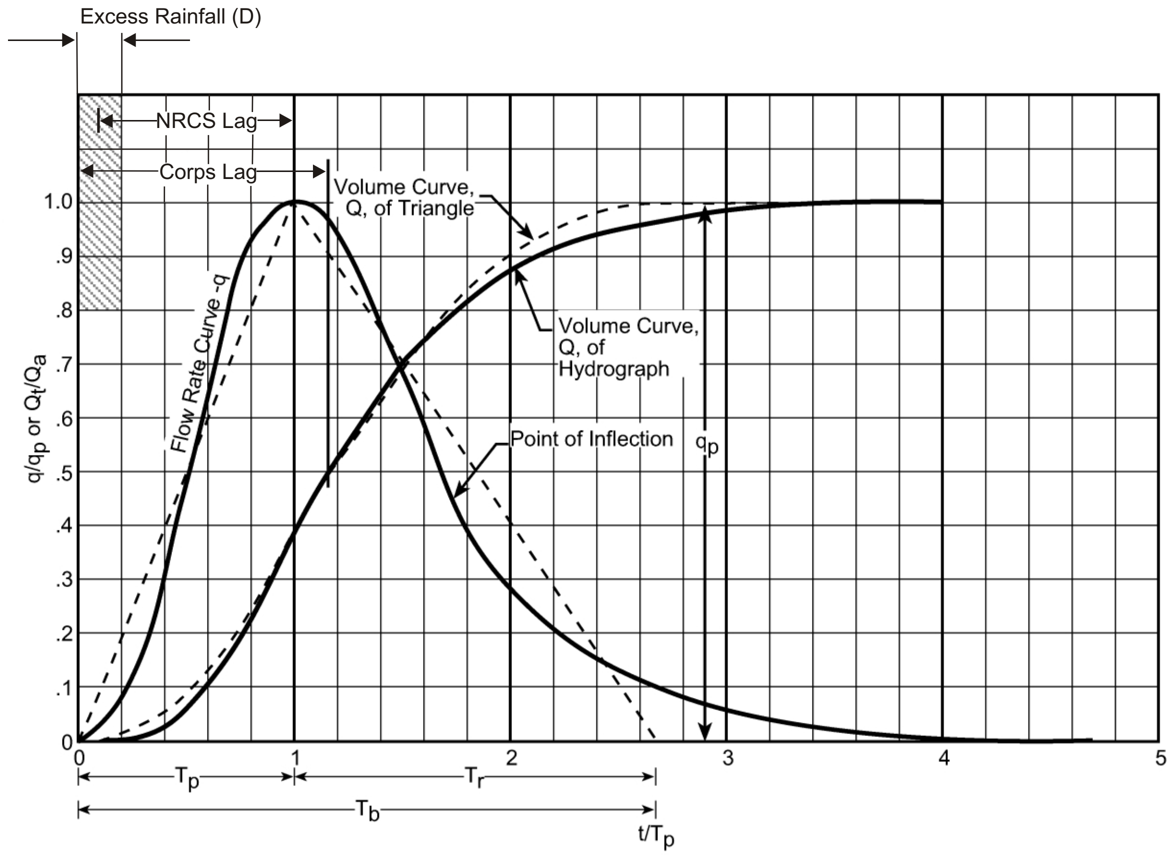
These relationships are useful in developing the peak rate equation for use with the dimensionless unit hydrograph.

Peak Rate Equation

From Figure 4-5 the total volume under the triangular unit hydrograph is:

$$Q_a = \frac{q_p\ T_p}{2} + \frac{q_p\ T_r}{2} = \frac{q_p}{2}(T_p + T_r) \qquad \text{(Eq. 4-5)}$$

or, $2Q_a = q_p\ (T_p + T_r)$



Ref: NEH4, March 1985

FIGURE

4-5

Dimensionless Curvilinear Unit Hydrograph and Equivalent Triangular Hydrograph

With Q_a in inches, T in hours, and area set at unity, solve for peak rate q_p.

$$q_p = \frac{2Q_a}{T_p + T_r} = \frac{2Q_a}{T_p\,(1.0 + T_r / T_p)} \qquad \text{(inches per hour)} \qquad \text{(Eq. 4-6)}$$

Let

$$K = \frac{2}{1 + \frac{T_r}{T_p}} \qquad \text{(Eq. 4-7)}$$

Therefore,

$$q_p = \frac{KQ_aA}{T_p} \text{ for a unit Drainage Area} \qquad \text{(Eq. 4-8)}$$

(A = 1 square mile)

In making the conversion from inches per hour to cubic feet per second and putting the equation in terms ordinarily used, including drainage area, A, in square miles, and the time, T, in hours, equation 4-12 becomes the general equation:

$$q_p = \frac{645.33\,K\,A\,Q_a}{T_p} \qquad \text{(Eq. 4-9)}$$

Where q_p is peak discharge in cubic feet per second and the conversion factor 645.33 changes square mile inches per hour to cubic feet per second.

The relationship of the triangular unit hydrograph, $T_r = 1.67\ T_p$, gives K = 0.75. Then substituting into equation 4-13 gives:

$$q_p = \frac{K_s\,A\,Q_a}{T_p} \qquad \text{(Eq. 4-10)}$$

with $K_s = 484$

K_s is a constant reflecting both the conversion of units and the shape of the hydrograph.

Any change in the dimensionless unit hydrograph reflecting a change in the percent of volume under the rising side would cause a corresponding change in the shape factor associated with the triangular hydrograph and therefore a change in the constant 484.

4.1.4.1 Curvilinear Unit Hydrographs

Obtaining constants for curvilinear hydrographs is similar to the procedure used for the triangular hydrograph. The total runoff volume (above the base flow) from the drainage area must be included in the hydrograph. Figure 4-6 shows the generalized curvilinear hydrograph.

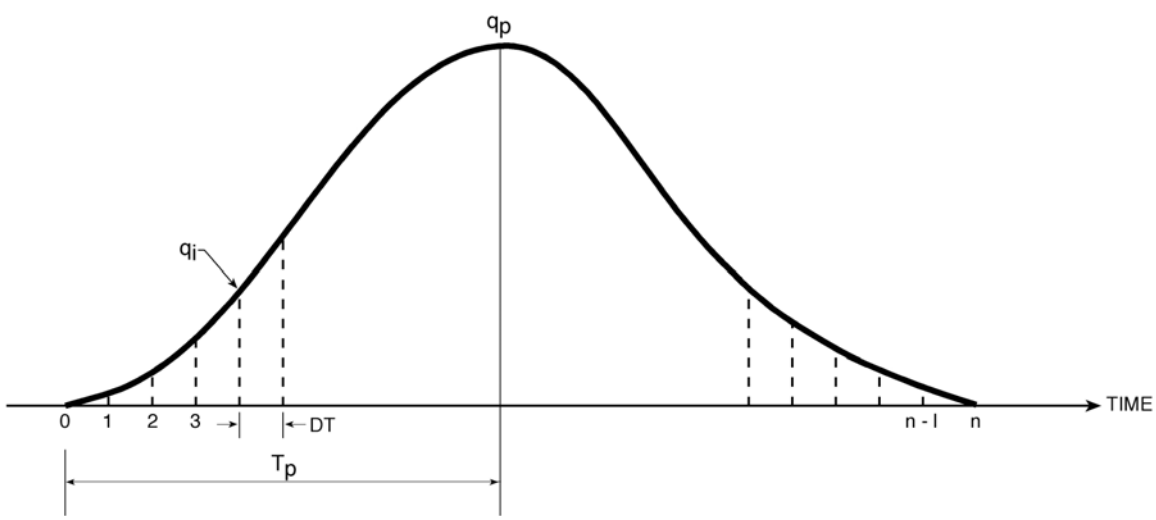


Figure 4-6. Trapezoidal Rule Illustration

q_i = the discharge in cubic feet per second at the end of time interval, i
DT = the length of the time interval in hours
q_p = the peak discharge that occurs at time T_p, as previously defined

Using the Trapezoidal Rule, the area under a curve is:

$$A = DX\left(\tfrac{1}{2} y_0 + y_1 + y_2 + \ldots\ldots\ldots\, y_{n-1} + \tfrac{1}{2} y_n\right)$$

If $y_0 = y_n = 0$, then $A = DX\left(\sum_{i=1}^{n-1} y_i\right)$.

Where A is the area, the y_i's are the ordinates to the curve, DX is the distance between ordinates, and n is the total number of ordinates.

To calculate the volume under the hydrograph curve using the trapezoidal rule:

$$y_i = q_i$$
$$DX = DT$$
$$V = DT\,(\textstyle\sum_{n=1}^{n-1} q_i) \qquad \text{(Eq. 4-11)}$$

where V is the volume in (cfs x hr)

If the following dimensionless ratios are used:

$$r_i = q_i/q_p$$
$$r_t = DT/T_p$$

Then the expression for V becomes

$$V = r_t\, T_p \textstyle\sum_{i=1}^{n} (r_i)\, q_p \qquad \text{(Eq. 4-12)}$$

This volume of the hydrograph is equal to the runoff volume from the drainage area:

$$V = Q_aAC \qquad \text{(Eq. 4-13)}$$

where: A = the drainage area in square miles

Q_a = accumulated direct runoff

C = a constant to convert from square mile inches per hour to cubic feet per second

C = (5280^2 ft^2 per $mile^2$) / (12 inches per foot x 3600 second per hour)

C = 645.33

therefore:

$$Q_aAC = r_t\, T_p \textstyle\sum_{i=1}^{n} (r_i)\, q_p \qquad \text{(Eq. 4-14)}$$

Solving for q_p:

$$q_p = Q_a AC / (r_t \, T_p \, \Sigma(r_i))$$

$$q_p = (C / (r_t \, \Sigma r_i)) \, (AQ_a / T_p)$$

$$q_p = K_s \, (AQ_a / T_P) \qquad \text{(Eq. 4-15)}$$

where: $K_s = 645 / (r_t \, \Sigma r_i)$ (Eq. 4-16)

K_s is a constant reflecting the units conversion and the shape of the hydrograph as previously defined in equation 4-14.

The summation of the ordinates (with r_t = 0.2) of the NRCS dimensionless unit hydrograph is 6.67 (Table 4-7). This gives a value of:

$$K_s = \frac{645}{(0.2/1)\,6.67} = 484$$

Note that this is the same value computed for the NRCS triangular unit hydrograph (Figure 4-5).

4.1.4.2 Unit Hydrograph Rain Duration

Figure 4-5 shows the relationship between the period of excess rainfall (D) and the resulting unit hydrograph. The ratio D/T_p is usually taken as about 0.2, but it can vary. Large values of D/T_p may result in irregularly shaped hydrographs.

4.1.5 Time to Peak and Lag Time

Time to peak and Lag time are shown on Figure 4-5. Note that there are two definitions of lag time shown on Figure 4-5. Lag time as defined by the United States Army Corps of Engineers (Corps lag) differs from lag time as defined by the NRCS (NRCS lag). The relationships between time to peak, Corps lag, NRCS lag, duration of effective rainfall, and time of concentration are discussed in Sections 4.1.5.1 through 4.1.5.5, below. Depending on the method that will be used for NRCS hydrologic method calculations (i.e., whether the engineer will use the SDUH Peak Discharge Program, HEC-1, or hand computation); either time to peak, Corps lag, or NRCS lag will be required. Additionally depending on the data available for the study (i.e., whether a time of concentration for the study watershed has been calculated based on a rational method study, or whether watershed physical characteristics will be used to calculate Corps lag), it may be necessary to convert one parameter to another. The following discussions will define each parameter and relationships between the parameters. Section 4.3 will identify when each parameter should be used and the relationships to be used to convert one parameter to another.

4.1.5.1 Time to Peak

Time to peak is defined as the elapsed time from the beginning of unit effective rainfall to the peak flow for the point of concentration. Time to peak is used when NRCS hydrologic method calculations are performed by the hand computation method described in Section 4.3. Time to peak must be determined in order to calculate the Unit Hydrograph ordinates, which are at intervals of t/T_p. T_p may be calculated for a watershed based on Corps lag or time of concentration (see Sections 4.1.5.2 and 4.1.5.5, respectively).

4.1.5.2 Corps Lag

The lag relationship given in this section (herein referred to as Corps lag or Corps T_l) is based upon criteria developed by the United States Army Corps of Engineers (United

States Army Engineer District Los Angeles Corps of Engineers, 1976). Corps lag for a drainage area can be defined as the elapsed time (in hours) from the beginning of unit effective rainfall to the instant that the summation hydrograph for the point of concentration reaches 50% of ultimate discharge. Corps lag is an empirical expression of the physical characteristics of a drainage area in terms of time. Corps lag can be expressed by the empirical formula:

$$\text{Corps } T_l \text{ (hours)} = 24\ \bar{n}\ ((L \times L_c) / s^{0.5})^m \qquad \text{(Eq. 4-17)}$$

where: L = length to longest watercourse (miles)

L_c = length along longest watercourse, measured upstream to a point opposite the watershed centroid (miles)

s = overall slope of drainage area between the headwaters and the collection point (feet per mile)

m = a constant determined by regional flood reconstitution studies (0.38 for San Diego County)

$\bar{n}$ = the average of the Manning's n values of the watercourse and its tributaries (see Section 4.3.5)

Figure 4-4 shows that 50% of ultimate discharge ($Q_t/Q_a = 0.5$) occurs at $t/T_p = 1.16$. Since Corps lag is defined as the time at which 50% of ultimate discharge occurs, Corps lag is related to T_p by the following equations:

$$\text{Corps } T_l = 1.16\ T_p \qquad \text{(Eq. 4-18)}$$

Or:

$$T_p = 0.862 \text{ Corps } T_l \qquad \text{(Eq. 4-19)}$$

for the typical NRCS dimensionless unit hydrograph.

4.1.5.3 NRCS Lag

Lag as defined by the NRCS for use with the NRCS dimensionless unit hydrograph (herein referred to as NRCS lag or NRCS T_l) differs from Corps lag. The NRCS lag of a watershed is defined as the time from the center of mass of excess rainfall to the time to peak of the unit hydrograph. NRCS lag is dependent on the period of effective rainfall (D) selected for the analysis. A small amount of variation is allowable in D, however D should be approximately $0.2T_p$. The center of mass of effective rainfall is found as (D/2).

NRCS lag is found by first determining T_p using one of the equations given above in Section 4.1.5.2 or below in Section 4.1.5.5, and then selecting an appropriate D for the study based on T_p. NRCS lag is then determined by the following equation:

$$\text{NRCS } T_l = T_p - D/2 \qquad \text{(Eq. 4-20)}$$

4.1.5.4 Relationship between Corps Lag and NRCS Lag

By combining equations 4-19 and 4-20 above, NRCS lag can also be calculated from Corps lag using the following relationship:

$$\text{NRCS } T_l = 0.862 \text{ Corps } T_l - D/2 \qquad \text{(Eq. 4-21)}$$

4.1.5.5 Relationships between T_p, T_c, and Corps Lag

When the lags determined from summation hydrographs for several gauged drainage areas are correlated to the hydrologic characteristics of the drainage areas, an empirical relationship is usually apparent. This relationship can then be used to determine the lags for comparable drainage areas for which the hydrologic characteristics can be determined, but for which the distribution graphs for concentration points cannot be determined because of inadequate hydrologic data. By comparing lag values (obtained from the analysis of rainfall-runoff data) to catchment T_c values estimated from a detailed RM analysis, a relationship is readily determined.

In McCuen (1982), NRCS T_p is related to T_c by:

$$T_p = 0.67\ T_c \qquad \text{(Eq. 4-22)}$$

Where T_c is defined in chapter 15 of NEH-4 as: 1) the time for runoff to travel from the furthermost point in the watershed to one point in question, and 2) the time from the end of excess rainfall to the point of inflection of the unit hydrograph.

From equation 4-18, Corp lag can be related to T_p:

$$\text{Corps } T_l = 1.16\ T_p$$

When equations 4-18 and 4-22 are combined, the result is:

$$\text{Corps } T_l = 1.16\ (0.67)\ T_c = 0.77\ T_c \qquad \text{(Eq. 4-23)}$$

The following relationship relating Corps lag to T_c, based on equation 4-23, was adopted for this manual:

$$\text{Corps } T_l = 0.8\ T_c \qquad \text{(Eq. 4-24)}$$

4.2 DEVELOPING INPUT DATA FOR NRCS HYDROLOGIC METHOD COMPUTATIONS

The following data is required for NRCS hydrologic method calculations: watershed area and physical characteristics, total rainfall amount, precipitation zone number, and runoff curve number. Sections 4.2.1 through 4.2.4 describe the development of input data. Section 4-3 describes the procedure for NRCS hydrologic method calculations.

4.2.1 Watershed, Geographic Location, Area, and Physical Characteristics

The watershed area and geographic location are determined from topographic maps and field surveys. For large drainage areas it might be necessary to divide the area into subareas to account for major land use changes, obtain analysis results at different points within the watershed area, combine hydrographs from different subareas as applicable, and/or route flows to points of interest. The highest elevation in the watershed (high point) and the elevation of the point of interest (low point) are determined from the map. The watershed length along the longest watercourse and the length to centroid are also read from the map. The centroid is the point in the watershed where approximately 50% of the watershed area is contributing to the watercourse. The length to centroid is measured from the low point of the watershed to the centroid.

4.2.1.1 Basin Factor ($\bar{n}$)

The basin $\bar{n}$ factor is the visually estimated mean of the n values (roughness values from Manning's formula) of all the channels within the basin area. A basin $\bar{n}$ factor can be estimated by comparing characteristics of drainage areas being studied with the characteristics of the drainage areas for which basin $\bar{n}$ factors have been estimated. Typical values of $\bar{n}$ range from 0.015 for areas that are mainly developed and have a large percentage of impervious area, to 0.100 for areas with extensive vegetation including vegetation in watercourses that slows water velocity.

The following descriptions are a guide for estimating the basin $\bar{n}$ factor, based on Plate 21, *Lag Relationships* from *Antelope Valley Streams Los Angeles County, California, Draft Survey Report, Hydrology Part I*, prepared by the U.S. Army Engineer District, Los Angeles Corps of Engineers (USACE, 1976):

$\bar{n}$ = 0.100: The drainage area has extensive vegetation, including grass, or is farmed with contoured plowing, and streams that contain a large amount of brush, grass or other vegetation that slows water velocity.

$\bar{n}$ = 0.050: Drainage area is quite rugged, with sharp ridges and narrow, steep canyons through which watercourses meander around sharp bends, over large boulders and considerable debris obstruction. The ground cover, excluding small areas of rock outcrops, includes many trees and considerable underbrush. No drainage improvements exist in the area.

$\bar{n}$ = 0.030: Drainage area is generally rolling, with rounded ridges and moderate side slopes. Watercourses meander in fairly straight, unimproved channels with some boulders and lodged debris. Ground cover includes scattered brush and grasses. No drainage improvements exist in the area.

$\bar{n}$ = 0.015: Drainage area has fairly uniform, gentle slopes with most watercourses either improved or along paved streets. Ground cover consists of some grasses with appreciable areas developed to the extent that a large percentage of the area is impervious.

The following additional references may also be helpful for determining an appropriate basin $\bar{n}$ factor: *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains* (USGS Water Supply Paper 2339) presents procedures for assigning reliable n values for channels and floodplains. This paper contains some photos, examples, and step-by-step procedures. The procedures can be used in the field. *Open Channel Hydraulics* by Ven Te Chow also provides guidance with tables of n values and photographs.

4.2.2 Rainfall and Precipitation Zone Number

The 6-hour and 24-hour rainfall amounts are taken from the isopluvial maps included in Appendix B. For large watersheds that intersect more than one isopluvial, the engineer may estimate a weighted average rainfall amount for the entire watershed. As described in Section 3.1.3, P_6 for the selected frequency should be between 45% and 65% of P_{24} for the selected frequency. If P_6 is not within 45% to 65% of P_{24}, P_6 should be increased or decreased as necessary to meet this criteria.

The PZN is taken from the map in Appendix C. As with the rainfall amount, the engineer may estimate a weighted average PZN for large watersheds.

4.2.3 Runoff Curve Number

The step by step procedure for calculating a composite CN is described in Table 4-8. A 2000-scale topographic map, and an NRCS hydrologic ground cover map and NRCS soil group map at the same scale are needed. The NRCS maps are available at the County of San Diego DPWFCS. A sheet of translucent vellum is also needed.

Step 5 of the procedure described in Table 4-8 involves tabulating data for different combinations of land use and soil group within the watershed. Data may be recorded on Worksheet 4-1 (provided in Appendix D). Composite CNs for the drainage area can be calculated by entering the data collected into a table such as the one provided as Worksheet 4-2 (provided in Appendix D) or a spreadsheet set up in a similar format (Worksheet headers presented as Table 4-9).

The composite CN for the total drainage area is then the sum of the composite CNs from column 6 of Worksheet 4-2 or Table 4-9.

Table 4-8

PROCEDURE FOR CALCULATION OF CURVE NUMBERS

Reference in Hydrology Manual	Procedure Step No.:	Refer to Example on Page:
Workbook Figure WB.3-1	1. Locate drainage area on 1":2000' scale USGS topographic map(s).	p. WB-31
Workbook Figure WB.3-1	2. Using a ½-inch or 1-inch grid (½ inch for areas less than 5 square miles) on a translucent overlay sheet, trace the drainage area boundary and other significant information from the topographic maps.	p. WB-31
Workbook Figures WB.3-2 and WB.3-3	3. Locate the drainage area on 1":2000' scale NRCS hydrologic ground cover and soil group maps available at the County of San Diego Department of Public Works Flood Control Section.	p. WB-32 p. WB-33
Workbook Figure WB.3-4	4. Overlay the grid sheet onto the ground cover and soil group maps; for each map, record the appropriate group cover (OB, NC, DL) and soil group (A, B, C, or D) at each grid intersection within the drainage area.	p. WB-34
Workbook Figure WB.3-4 Appendix D, Worksheet 4-1	5. For each combination of ground cover/soil group, count and record the number of grid intersections where that combination occurs.	p. WB-31, Appendix WB.A, Worksheet 4-1
Appendix D, Worksheet 4-1	6. Compute the total number of grid intersections within the drainage area. For a 1-inch grid, each intersection represents 1 square inch on the maps, and the total area of the drainage area is found by scale conversion. For the ½-inch grid, each intersection is ¼ square inch. Compute the total area of the drainage area.	p. WB-31, Appendix WB.A, Worksheet 4-1
Tables 4-3, 4-4, 4-5	7. By field inspection, determine the hydrologic conditions that exist in the drainage area for each type of ground cover.	p. 4-15
Appendix D, Worksheet 4-2, Column 5	8. For each ground cover/soil group combination, compute the fraction of the total area represented by that combination by the ratio of the number of grid intersections counted in step 5 to the total grid intersections (step 6).	p. WB-35, Appendix WB.A, Worksheet 4-2

Table 4-8 (Continued)

PROCEDURE FOR CALCULATION OF CURVE NUMBERS

Reference in Hydrology Manual	Procedure Step No.:	Refer to Example on Page:
Table 4-2 Appendix D, Worksheet 4-2, Column 4	9. For each ground cover/soil group/hydrologic condition combination, select the appropriate runoff CN for PZN Condition = 2.0, the CN_2.	p. 4-10, Appendix WB.A, Worksheet 4-2
Appendix D, Worksheet 4-2, Column 6	10. Compute the partial CN_2 for each combination by the product of area fraction of each combination from step 8 and the selected CNs from step 9.	Appendix WB.A, Worksheet 4-2
Appendix D, Worksheet 4-2, Column 6	11. Sum the partial CN_2's to obtain the CN_2 for the entire drainage area.	Appendix WB.A, Worksheet 4-2
	12. If applicable to the study, to determine the CN for future land uses, modify existing ground cover designations and use same procedures.	

Table 4-9

Worksheet Headers for
Composite Curve Number Calculations

column 1	column 2	column 3	column 4	column 5	column 6
GROUND COVER/ LAND USE	HYDROLOGIC CONDITION (field inspection)	SOIL GROUP	CN_2 (Table 4-2)	FRACTION OF AREA A_i/A	PARTIAL CN_2 $CN_2 \times A_i/A$

The following discussion gives some guidance based on TR-55 for adjusting CNs for different types of impervious areas. These adjustments may be used where relevant for urbanized areas that have unconnected impervious areas or where the values of percentage of impervious area are not applicable. Section 4.2.4 describes adjustment of the CN for PZN Condition (required for all NRCS hydrologic method studies).

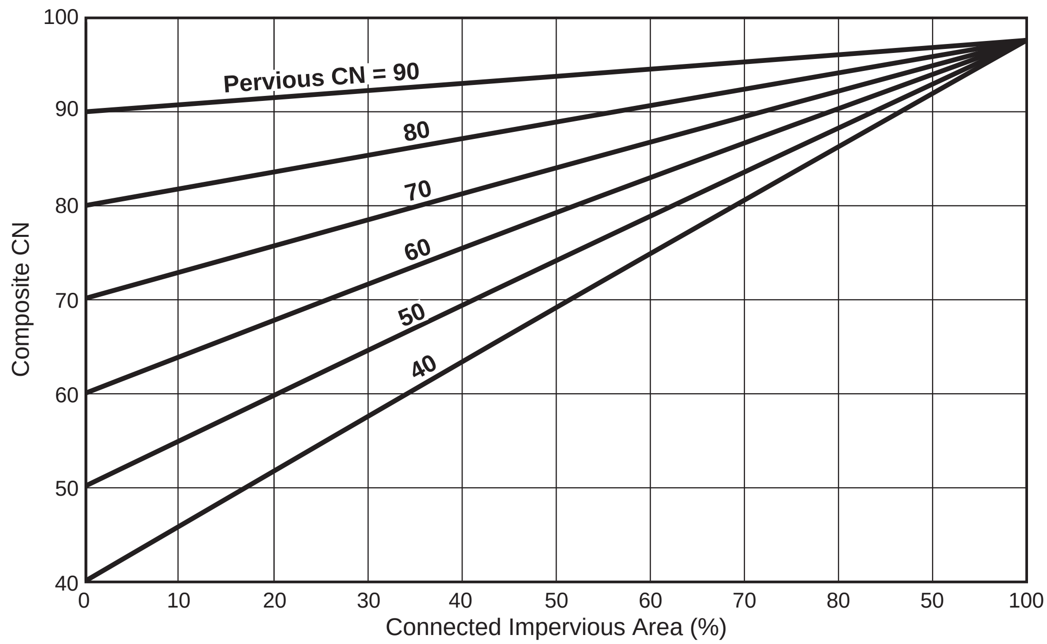
4.2.3.1 Connected Impervious Areas

The CN values given in Table 4-2 for urban land uses are based on directly connected impervious areas and specific assumed percentages of impervious area. An impervious area is considered directly connected if runoff from it flows directly into the drainage system. It is also considered directly connected if runoff from it occurs as concentrated shallow flow that runs over pervious areas (such as flow in a swale) and then into a drainage system. The CN values given in Table 4-2 were developed on the assumptions that:

(a) pervious urban areas are equivalent to pasture in good hydrologic condition, and

(b) impervious areas have a CN of 98 and are directly connected to the drainage system.

If all of the impervious area is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in Table 4-2 are not applicable, use Figure 4-7 to compute a composite CN. For example, Table 4-2 gives a CN of 70 for a 0.5-acre lot in hydrologic soil group B, with an assumed impervious area of 25%. However, if the lot has 20% impervious area and a pervious area CN of 61, the composite CN obtained from Figure 4-7 is 68. The CN difference between 70 and 68 reflects the difference in percent impervious area.



SOURCE: TR-55, Second Ed. June 1986

Composite CN with Connected Impervious Areas

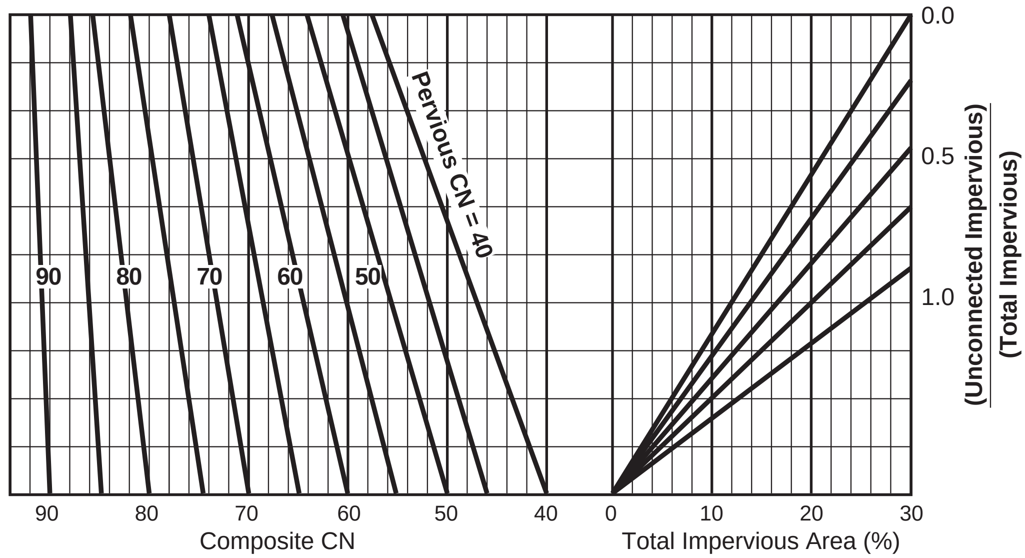
F I G U R E

4-7

4.2.3.2 Unconnected Impervious Areas

Runoff from these areas is spread over a pervious area as sheet flow. To determine CN when all or part of the impervious area is not directly connected to the drainage system, (1) use Figure 4-8 if total impervious area is less then 30% or (2) use Figure 4-7 if the total impervious area is equal to or greater than 30%, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.

When impervious area is less than 30%, obtain the composite CN by entering the right half of Figure 4-8 with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN. For example, for a 0.5-acre lot with 20% total impervious area (75% of which is unconnected) and pervious CN of 61, the composite CN from Figure 4-8 is 66. If all of the impervious area is connected, the resulting CN (from Figure 4-7) would be 68.



SOURCE: TR-55, Second Ed. June 1986

Composite CN with Unconnected Impervious Areas
(Total Impervious Area Less Than 30%)

FIGURE

4-8

4.2.4 PZN Condition

The CNs provided in Table 4-2 are for PZN Condition 2.0 (PZN adjustment factor = 2.0). After the CN has been calculated for the study area, it must be adjusted for PZN Condition. This adjustment is required for NRCS hydrologic method studies. The PZN adjustment factors (described in Section 4.1.3 and provided in Table 4-6) are based on the storm frequency and the precipitation zone that the watershed is located in. To adjust the CN for PZN Condition, first determine the appropriate PZN adjustment factor for the combination of storm duration and precipitation zone for the study. For precipitation zone numbers not equal to 1.0, 2.0, 3.0, and 4.0 (Coast, Foothills, Mountains, and Desert), interpolate the PZN adjustment factor between the zones. Interpolation, if necessary, is linear. For example, for a 100-year storm duration for a study area with a PZN of 1.5, the PZN adjustment factor interpolated from the values in Table 4-6 is 2.5. After determining the appropriate PZN adjustment factor, use Table 4-10 to determine the adjusted CN for the study area for the appropriate PZN Condition. If the appropriate PZN Condition for the study area based on the storm duration and PZN is 2.0 (PZN adjustment factor = 2.0), no adjustment is necessary because the CNs provided in Table 4-2 are for PZN Condition 2.0. For PZN adjsutment factor equal to 1.0 or 3.0, locate the CN value for PZN Condition 2.0 and read the adjusted CN value for PZN Condition 1.0 or 3.0 from the same row of the table. For PZN adjsutment factor not equal to 1.0, 2.0, or 3.0, interpolate the CN between the value for PZN Condition 2.0 and the value for the appropriate PZN Condition in the same row of the table. Interpolation, if necessary, is linear.

Table 4-10

RUNOFF CURVE NUMBERS FOR PZN CONDITIONS 1.0, 2.0, AND 3.0

CN For:			CN For:		
PZN Condition = 1.0	PZN Condition = 2.0	PZN Condition = 3.0	PZN Condition = 1.0	PZN Condition = 2.0	PZN Condition = 3.0
100	100	100	40	60	78
97	99	100	39	59	77
94	98	99	38	58	76
91	97	99	37	57	75
89	96	99	37	56	75
87	95	98	34	55	73
85	94	98	34	54	73
83	93	98	33	53	72
81	92	97	32	52	71
80	91	97	31	51	70
78	90	96	31	50	70
76	89	96	30	49	69
75	88	95	29	48	68
73	87	95	28	47	67
72	86	94	27	46	66
70	85	94	26	45	65
68	84	93	25	44	64
67	83	93	25	43	63
66	82	92	24	42	62
64	81	92	23	41	61
63	80	91	22	40	60
62	79	91	21	39	59
60	78	90	21	38	58
59	77	89	20	37	57
58	76	89	19	36	56
57	75	88	18	35	55
55	74	88	18	34	54
54	73	87	17	33	53
53	72	86	16	32	52
52	71	86	16	31	51
51	70	85	15	30	50
50	69	84			
48	68	84	12	25	43
47	67	83	9	20	37
46	66	82	6	15	30
45	65	82	4	10	22
44	64	81	2	5	13
43	63	80	0	0	0
42	62	79			
41	61	78			

4.3 PROCEDURE FOR NRCS HYDROLOGIC METHOD COMPUTATIONS

NRCS hydrologic method computations are based on the concepts and equations presented in Section 4.1. Several computer programs, including the public domain computer programs HEC-1 and HEC-HMS, model these equations. Additionally, the AES software company has prepared a program to calculate peak flows using these equations and has provided this program to the County of San Diego for use with this manual. The purpose of the San Diego Unit Hydrograph (SDUH) Peak Discharge Program is the same as the peak flow charts provided in the 1993 edition of this manual, to provide engineers with the option of determining the peak flow without the need for hand calculations, thus reducing the time and effort needed in watershed studies and improving consistency between studies. As with the peak flow charts, the SDUH Peak Discharge Program output provides a peak flow only, and does not provide a hydrograph. The following steps describe the procedure for performing NRCS hydrologic method calculations:

1. Determine lag time and/or time to peak, and computation interval
2. Prepare incremental rainfall distribution
3. Calculate excess rainfall
4. Develop hydrograph of direct runoff from the drainage area

These steps are discussed in Sections 4.3.1 through 4.3.4 below. The SDUH Peak Discharge Program will perform Steps 2 through 4, and may be used if a hydrograph is not required. Worksheet 4-3 (provided in Appendix E) sets up the input data for the SDUH Peak Discharge Program. The SDUH Peak Discharge Program is provided on the cd that accompanies this manual. Follow the directions on the cd for installation of the SDUH Peak Discharge Program on a personal computer. HEC-1 or HEC-HMS will perform Steps 3 and 4. Other computer programs may be used provided a detailed output and description is provided.

4.3.1 Step 1: Determine Lag Time and/or Time to peak, and Computation Interval

To perform NRCS hydrologic method calculations, the lag time and/or T_p for the watershed must be calculated first. Concepts and equations for lag time and T_p are presented in Section 4.1.5. If a hand calculation will be used to determine the peak flow for the study, T_p is needed. If the SDUH Peak Discharge Program will be used to determine the peak flow for the study, Corps lag is needed. If HEC-1 will be used to determine the flow for the study, NRCS lag is needed. HEC-1 requires NRCS lag as the input parameter TLAG that is used with the SCS (NRCS) dimensionless unit hydrograph method (HEC-1 Flood Hydrograph Package User's Manual). The period of effective rainfall (D) is the same as the computation interval (HEC-1 variable NMIN or JXMIN), and must be specified on the IT or IN card of the HEC-1 input file.

Lag time (Corps lag or NRCS lag) and T_p may be calculated based on the T_c to the point of interest or based on watershed characteristics, depending on the type of study and data available. Section 4.3.1.1 describes the method for calculating T_p and/or NRCS lag based on Corps lag, which can be calculated based on the watershed physical characteristics. Section 4.3.1.2 describes the method for calculating T_p based on T_c for studies that are transitioned from the RM or MRM to the NRCS hydrologic method. Corps lag or NRCS lag for a basin may also be calculated based on T_c if needed.

4.3.1.1 Calculation of Time to Peak Using Corps Lag

To calculate T_p using Corps lag, with Corps lag calculated based on watershed physical characteristics, use the empirical formula given in equation 4-17 for Corps lag, where watershed length (L) and length to centroid (L_c) are in miles and watershed slope (s) is in feet per mile (see Section 4.1.5.2).

$$\text{Corps } T_l \text{ (hours)} = 24\ \bar{n}\ ((L \times L_c) / s^{0.5})^m$$

Once Corps lag has been determined, T_p is calculated using equation 4-19:

$$T_p = 0.862 \text{ x Corps } T_l$$

If NRCS lag is needed, it is calculated using equation 4-20:

$$\text{NRCS } T_l = T_p - D/2$$

4.3.1.2 Calculation of Time to Peak Using Time of Concentration

When a RM study is transitioned to an NRCS hydrologic method study, it may be more convenient to continue calculating T_c for each reach of the study and relate T_p to T_c. To extend T_c along a reach of a study, estimate the velocity for the reach using Manning's formula (Figure 3-7) and estimated channel geometry for the reach. Calculate T_t in the reach (length divided by velocity), and add T_t to the previous T_c to obtain the T_c for the point at the end of the reach.

Once T_c has been determined, T_p is calculated using equation 4-22:

$$T_p = 0.67\ T_c$$

It is noted that the RM T_c, used for the estimation of T_p, is a critical parameter in the unit hydrograph method. Extreme care must be taken in the evaluation of the watershed T_c in order to reduce uncertainty and enable "reproducibility" of this parameter.

If needed, NRCS lag can then be calculated using equation 4-20:

$$\text{NRCS } T_l = T_p - D/2$$

If needed, the Corps lag may also be calculated based on T_c. As discussed above in Section 4.1.5, the relationship of Corps $T_l = 0.8\ T_c$ (equation 4-24) was adopted for this manual.

4.3.2 Step 2: Prepare Incremental Rainfall Distribution

Creation of the 24-hour nested storm rainfall distribution requires rainfall depths for increments of storm duration from the selected computation interval through 24 hours (e.g., to create the nested storm using a 15-minute computation interval, rainfall depths are required for durations equal to 15 minutes, 30 minutes, 45 minutes, 1 hour, 1.25 hours, and so on through 24 hours). The computation interval is the period of excess rainfall (D) and should be approximately $\leq 0.2T_p$.

Total rainfall amounts for the 6-hour duration and 24-hour duration shall be read from the isopluvial maps located in Appendix B. As described in Section 3.1.3, P_6 for the selected frequency should be between 45% and 65% of P_{24} for the selected frequency. If P_6 is not within 45% to 65% of P_{24}, P_6 should be increased or decreased as necessary to meet this criterion.

For increments of duration less than 6 hours, total rainfall for the duration shall be computed by calculating the intensity for the duration using the intensity-duration design equation presented in Section 3, and multiplying the intensity by the duration. For each duration:

$$I = 7.44\ P_6\ D^{-0.645} \qquad \text{(Eq. 4-25)}$$

and:

$$P = I\ (D/60) \qquad \text{(Eq. 4-26)}$$

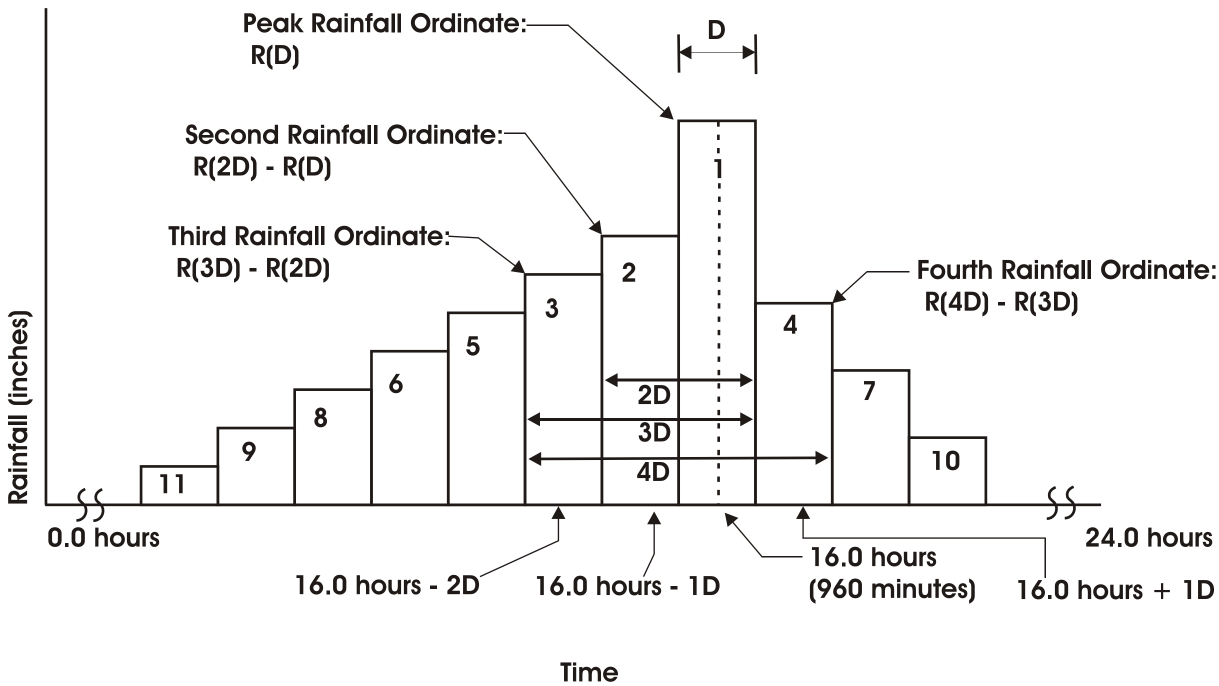
where D is the duration in minutes, P is the total rainfall depth for the duration. The expression (D/60) is the duration converted to units of hours. The intensity equation is based on the duration (D) in minutes, and the resulting units of intensity are inches per hour. By multiplying intensity in inches per hour by the duration in hours, rainfall depth in units of inches is obtained.

For increments of duration between 6 hours and 24 hours, total rainfall depth may be interpolated between the 6-hour and 24-hour rainfall values using log-log interpolation, or read from a log-log chart by extending a straight line on log-log paper between the 6-hour and 24-hour rainfall values. Record the total rainfall depth for each duration in order of increasing duration.

Next, adjust the total rainfall depth for each duration using the appropriate depth-area adjustment values based on the watershed area (multiply the rainfall amount by the depth-area adjustment factor). For durations less than 30 minutes, use the 30-minute depth area adjustment value. For durations greater than 30 minutes and not equal to durations with data available on Figure 4-2 and Table 4-1, interpolate the depth area adjustment between the surrounding data points on Table 4-1. Interpolation, if necessary, is linear.

Next, create the ordinates of the hyetograph using the depth-area adjusted total rainfall amounts. Figure 4-9 shows the construction of the hyetograph. The first ordinate "R(D)" is the depth-area adjusted total rainfall amount for the first time increment. The second ordinate "R(2D) –R(D)" is the depth-area adjusted total rainfall amount for the second time increment minus the depth-area adjusted total rainfall amount for the first time increment. The third ordinate "R(3D) –R(2D)" is the depth-area adjusted total rainfall amount for the third time increment minus depth-area adjusted total rainfall amount for the second time increment, and so on. Note: the sum of the ordinates of the hyetograph should be equal to the depth-area adjusted total rainfall amount for duration = 24 hours.

Finally, sort the ordinates of the hyetograph into the order of the (2/3, 1/3) distribution. The first ordinate (calculated above, the depth-area adjusted incremental rainfall amount for the first time increment) is the peak rainfall ordinate. This peak rainfall ordinate occurs at hour 16.0 of the 24-hour storm. The second rainfall ordinate (calculated above) occurs at 16.0 hours – 1D, the third rainfall ordinate (calculated above) occurs at 16.0 hours – 2D, and the fourth rainfall ordinate (calculated above) occurs at 16.0 hours + 1D. The sequence continues alternating two ordinates to the left and one ordinate to the right (see Figure 4-9).



Construction of Hyetograph

FIGURE

4-9

4.3.3 Step 3: Calculate Excess Rainfall

Excess rainfall is calculated using equation 4-4. Excess rainfall must be calculated for a cumulative rainfall series. Because equation 4-4 is subject to the limitation, $P \geq 0.2S$, calculation of excess rainfall based on the ordinates of the hyetograph (which are incremental rainfall amounts) will result in underestimation of excess rainfall because the incremental rainfall amounts are small. To calculate excess rainfall, create a cumulative rainfall series by summing the ordinates of the hyetograph. This must be performed after the ordinates have been sorted into the (2/3, 1/3) distribution (see above). Calculate each excess rainfall ordinate from the cumulative rainfall series using equation 4-4.

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

Note: the last ordinate of the series should be equal to the excess runoff from the depth-area adjusted incremental rainfall amount for duration = 24 hours.

Finally, create incremental amounts of excess rainfall from the cumulative series.

Table 4-11 gives values of S and $P \geq 0.2S$ for the curve numbers.

Table 4-11

RUNOFF CURVE NUMBERS AND CONSTANTS FOR THE CASE I_A=0.2S

CN	S (inches)	Curve Starts Where P = (inches)	CN	S (inches)	Curve Starts Where P = (inches)
100	0	0	60	6.67	1.33
99	.101	.02	59	9.95	1.39
98	.204	.04	58	7.24	1.45
97	.309	.06	57	7.54	1.51
96	.417	.08	56	7.86	1.57
95	.526	.11	55	8.18	1.64
94	.638	.13	54	8.52	1.70
93	.753	.15	53	8.87	1.77
92	.870	.17	52	9.23	1.85
91	.989	.20	51	9.61	1.92
90	1.11	.22	50	10.0	2.00
89	1.24	.25	49	10.4	2.08
88	1.36	.27	48	10.8	2.16
87	1.49	.30	47	11.3	2.26
86	1.63	.33	46	11.7	2.34
85	1.76	.35	45	12.2	2.44
84	1.90	.38	44	12.7	2.54
83	2.05	.41	43	13.2	2.64
82	2.20	.44	42	13.8	2.76
81	2.34	.47	41	14.4	2.88
80	2.50	.50	40	15.0	3.00
79	2.66	.53	39	15.6	3.12
78	2.82	.56	38	16.3	3.26
77	2.99	.60	37	17.0	3.40
76	3.16	.63	36	17.8	3.56
75	3.33	.67	35	18.6	3.72
74	3.51	.70	34	19.4	3.88
73	3.70	.74	33	20.3	4.06
72	3.89	.78	32	21.2	4.24
71	4.08	.82	31	22.2	4.44
70	4.28	.86	30	23.3	4.66
69	4.49	.90			
68	4.70	.94	25	30.0	6.00
67	4.92	.98	20	40.0	8.00
66	5.15	1.03	15	56.7	11.34
65	5.38	1.08	10	90.0	18.00
64	5.62	1.12	5	190.0	38.0
63	5.87	1.17	0	infinity	infinity
62	6.13	1.23			
61	6.39	1.28			

4.3.4 Step 4: Develop Hydrograph of Direct Runoff from the Drainage Area

The hydrograph of direct runoff from the drainage area is developed as follows:

First, the unit hydrograph ordinates are created based on the T_p and the unit hydrograph q_p for the study area. T_p was calculated in step 1 (see Section 4.3.1). The unit hydrograph q_p is then calculated using equation 4-10:

$$q_p = \frac{K_s\ A\ Q_a}{T_p}$$

where:

K_s = 484, a constant reflecting both the conversion of units and the shape of the hydrograph
Q_a = 1 inch of effective runoff
A = watershed area (square miles)

Next, set up the unit hydrograph ordinates t/T_p and q/q_p. The time increment (t) for unit hydrograph ordinates must be the same duration as the period of effective rainfall selected for the rainfall ordinates (D). For multiples of t, compute t/T_p until $t/T_p = 5$. For each t/T_p, find the corresponding q/q_p from Table 4-7. For values of t/T_p that are not given on Table 4-7, read the corresponding values of q/q_p from Figure 4-4 or interpolate from the nearest values from Table 4-7. Next, compute the unit hydrograph q for each ordinate.

Set up a table with the unit hydrograph q ordinates in rows and incremental excess rainfall ordinates in columns. Table 4-12 provides an abbreviated sample table with letters for column identification and numbers for row identification that correspond with the discussion below describing convolution of the unit hydrograph. A complete example is provided in the Workbook of Sample Problems provided at the end of this manual. Convolution of the unit hydrograph is performed as follows:

1. Multiply the effective rainfall depth for the first unit time period (column C, row 2) by each unit hydrograph ordinate q (column B, rows 4 through 9) to determine the flood hydrograph which would result from that increment of effective rainfall.
2. Repeat the above process for each succeeding effective rainfall depth (columns D through H) advancing the resultant flood hydrographs one unit time period for each cycle.
3. Sum the flow ordinates found in the steps above across the rows to determine the average flow ordinates per unit time period for the design storm flood hydrograph (column I).

Table 4-12

SAMPLE TABLE FOR CONVOLUTION OF UNIT HYDROGRAPH

Row/Column Identification	A	B	C	D	E	F	G	H	I
1		**Time (minutes)**	15	30	45	60	75	90	
2		**Effective Rainfall Ordinate (inches)**	0.00	0.01	0.02	0.04	0.05	0.07	
3	**Time, t (minutes)**	**Unit Hydrograph Ordinate, q**							**Flood Hydrograph Ordinate (cfs)**
4	15	119	0.00						0.00
5	30	339	0.00	1.19					1.19
6	45	705	0.00	3.39	2.38				5.77
7	60	1158	0.00	7.05	6.78	4.76			18.59
8	75	1422	0.00	11.58	14.10	13.56	5.95		45.19
9	90	1500	0.00	14.22	23.16	28.20	16.95	8.33	90.86

Note: This Table represents an abbreviated example. A complete example is included in the Workbook Section of this manual.

4.4 TRANSITION FROM RATIONAL METHOD TO NRCS HYDROLOGIC METHOD

As discussed in Section 3, the engineer should only use the RM or MRM for drainage areas up to approximately 1 square mile. The NRCS hydrologic method should be used for study areas approximately 1 square mile and greater in size. For study areas greater than approximately 1 square mile, the NRCS hydrologic method may be used for the entire study area, or the RM or MRM may be used for approximately 1 square mile of the study area and then transitioned to the NRCS hydrologic method using the procedure described below:

- Stop RM calculations at approximately 1 square mile.

- Freeze RM peak discharge, Q_p, at approximately 1 square mile.

- Begin NRCS hydrograph calculations at the next point of interest. Estimate the travel time, T_t, from the MRM calculations along the reach to the point of interest, and increase the T_c from the MRM calculations by T_t. Determine T_p based on T_c using equation 4-22. Perform NRCS calculations using T_p and the total watershed area to the point of interest (Note: if the SDUH Peak Discharge Program will be used for the NRCS calculations, convert T_p to Corps lag using equation 4-18, or if HEC-1 will be used for the NRCS calculations, convert T_p to NRCS lag using equation 4-20).

If $Q_{MRM} > Q_{NRCS}$ then use Q_{MRM}.

If $Q_{MRM} < Q_{NRCS}$ then use Q_{NRCS}.

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SECTION 5
EROSION AND SEDIMENTATION

5.1 LIMITATION AND APPLICATION

This section should be useful to the engineer analyzing the erosion potential of a site and sizing desiltation structures, or in applying other erosion protection devices to a project. Municipal agency staff members may also use this section when reviewing project plans and studies. The focus of this section is to provide an outline for the prediction of sedimentation yield that occurs during rainfall events in a study area. Once the sedimentation yield is quantified, there are suggested methods and/or devices that must be chosen to limit the transport of sediments. These must be incorporated into the design of the project. The explanation and calculations for anticipated sedimentation yield and the recommended devices should be included in any drainage or hydrology study prepared for a project.

5.2 SEDIMENTATION

5.2.1 Introduction

Sedimentation begins with the first splash of a raindrop onto soil. The impact of the raindrop may displace a soil particle on the ground, depending on the cohesion or stability of the material. Once the soil particle is displaced, the particle may remain suspended in the raindrop for a period of time. In general, the soil particle will remain in suspension until the raindrop (1) slows down to a sufficient velocity to allow the particle to fall out of suspension, (2) is absorbed into the ground, or (3) evaporates. Erosion intensifies during significant storm events lasting for long periods of time. Soil may become saturated after long rainfall, allowing raindrops to sheet-flow over it. Raindrops then follow the natural terrain and are combined with other raindrops carrying suspended particles as well. Once the raindrops combine, they become a trickle, gully, stream, and eventually a river. This process can lead to the transportation of large amounts of soil particles downstream. As seen in Figure 5-1, erosion can, has, and will likely change the terrain, undermine structures, alter the capacity of storm drain infrastructure, cause damage to property, and may cause loss of life.

The ability to predict yield and determine methods required to control sediments has improved over the last 50 years. Many erosion control devices stem from historical ideas of farmers whose soils and crops were being degraded by erosion. The importance of preserving soil on development projects has become just as important as on croplands. Examples of erosion control devices can be found in Section 5.4.

Sedimentation is generally a natural process, but it is accelerated by man's activities. During construction of development projects, scarification and grading of topsoil is performed by machinery. These actions remove natural vegetation that would normally absorb some stormwater and assist in holding soil together with root structures. The entire area is subject to severe sedimentation after a rainstorm once vegetation is removed or soil is disturbed. Every effort should be made to estimate the sedimentation yield and install devices that limit erosion or capture eroded soil.

5.2.2 Supplemental References

The following references are suggested reading material. The references listed are not meant to be inclusive, but are a sample of available material to supplement the engineer's experience when making decisions about sedimentation yield.

(a) *Biotechnical Slope Protection and Erosion Control, Donald L. Gray and Andrew T. Leiser, 1982.*

(b) *Erosion and Sedimentation in San Diego County Watersheds, Department of Water Resources, State of California, 1977.*

(c) *Soil Erosion: Prediction and Control, Soil Conservation Society Publication 21, Wischmeier, W.H., 1977.*

Example of Urban Erosion

FIGURE

5-1

Figure 5-1, Page 2 of 2 Color

"Example of Urban Erosion"

(d) *Predicting Rainfall Erosion Losses – A Guide to Conservation Planning, Agriculture Handbook Number 537, Wischmeier, W.H. and D.D. Smith, 1978.*

(e) *Sedimentation Engineering, Manual No. 54, ASCE, 1975.*

Attending seminars that focus on sedimentation, such as those presented by the International Erosion Control Association (IECA), may also prove useful. For information about these seminars contact:

International Erosion Control Association
P.O. Box 4904
Steamboat Springs, CO 80477
Phone (303) 879-3010
Fax (303) 879-8563

5.2.3 Near-term and Long-term Soil Loss Calculations

When an engineer is developing a hydrology study for a project, the study shall include two calculations. The first calculation addresses "near-term" sedimentation yield. Near-term refers to the construction phase of the project. During construction, significant erosion potential exists. Near-term erosion is generally controlled by installing devices such as gravel bags, straw waddles, silt fences, hay bales, trenches, desiltation basins, fiber blankets, and hydroseed.

The second calculation addresses "long-term" sedimentation yield. After construction, erosion may still be an issue. Long-term erosion potential is dependent on the terrain, slope gradients, vegetative cover, root type, type of exposed soil, and intensity of rainfall experienced at the site. If an engineer finds that a site has a potential for long-term erosion, permanent desiltation basins (or other devices) that will prevent the transport of sediments through storm drain infrastructure should be installed.

5.2.4 Methods of Soil Loss Prediction

Predicting soil losses is a science based on methods using interpolation of historic data, laboratory results, and derivation of formulas. There are a number of existing methods used to quantify soil losses. Examples include:

(a) Universal Soil Loss Equation (USLE)
(b) Flaxmans Method
(c) Chemicals, Run-off, and Erosion from Agriculture Management Systems (CREAMS model)
(d) Erosion-Productivity Impact Calculator (EPIC)
(e) Simulator for Water Resources in Rural Basins (SWRRB)
(f) Water Erosion Prediction Project (WEPP) model
(g) Anderson's Method
(h) Branson and Owen's Equation
(i) Renard's Equation
(j) Tatum's Method
(k) Neger's Method

In general, the County of San Diego supports the USLE method in predicting soil losses. The USLE is widely used throughout the United States. This method produces accurate volumes of soil losses if the equation, graphs, and tables are used appropriately. It is also important that the engineer performs research to find the information required to use the nomographs and tables that produce the factors used in the equation.

An engineer should meet with the agency for approval before preparing sedimentation yield calculations using a method other than the USLE. The engineer should request an alternate method if it is his/her opinion that the alternate method would result in calculation of more accurate quantities. If the alternate method is approved by the agency, the engineer shall describe the alternate method in the study/report. The engineer shall explain the steps used, including applicable portions of reference material used, and reasons for choosing the alternate method.

5.2.5 Basic Soil Loss Table

The County of San Diego accepts soil loss predictions using Table 5-1. Once the engineer identifies the average slopes and acreage of disturbed soil of a project, a resulting soil loss may be calculated. This table involves interpolation, but generally produces volumes more conservative than the USLE.

5.2.6 Universal Soil Loss Equation

The USLE was derived by Wischmeier and Smith in 1965 while working for the Agricultural Research Service (ARS). The ARS then performed significant research to estimate and fine-tune factors in the equation. The original purpose of the USLE was to predict soil losses in croplands east of the Rocky Mountains. However, the USLE was modified so that it could be used in different regions of the United States, including California. The USLE accounts for all known factors affecting rainfall erosion and is generally accepted by local industry. The USLE is:

$$A_s = RKLsCP$$

where:

A_s = the computed soil loss in tons (dry weight)
R = the rainfall erosion index for the given storm period
K = the soil erodibility factor
L = the slope length factor
s = the slope gradient factor
C = cropping management (vegetation) factor
P = erosion control practice factor

Table 5-1

BASIC SOIL LOSS TABLE
(in cubic yards)*

TRACT AREA (acres)	AVERAGE SLOPES					
	2%	5%	8%	10%	12%	15%
10	270	350	370	400	450	500
15	400	420	460	600	675	750
20	540	700	740	800	900	1000
40	1080	1400	1480	1600	1800	2000
80	2160	2800	2960	3200	3600	4000
100	2700	3500	3700	4000	4500	5000
150	4000	4200	4600	6000	6750	7500
200	5400	7000	7400	8000	9000	10000

*Engineer shall interpolate the figures listed in the table as required.

5.2.6.1 Rainfall Erosion Index (*R*)

The R factor is an index associated with the mean annual rainfall experienced at a particular location. An engineer should first calculate the intensity of a 2-year, 6-hour storm event for a project using the isopluvials of the San Diego Region (Appendix B). Once the intensity is found, plot the value on Figure 5-2 to find the mean annual R Factor. Use line I as the pivot-point. This line applies to the San Diego Region. Lines IA and II apply to northern California and the eastern deserts, respectively. Refer to Figure 5-3.

5.2.6.2 Soil Erodibility Factor (*K*)

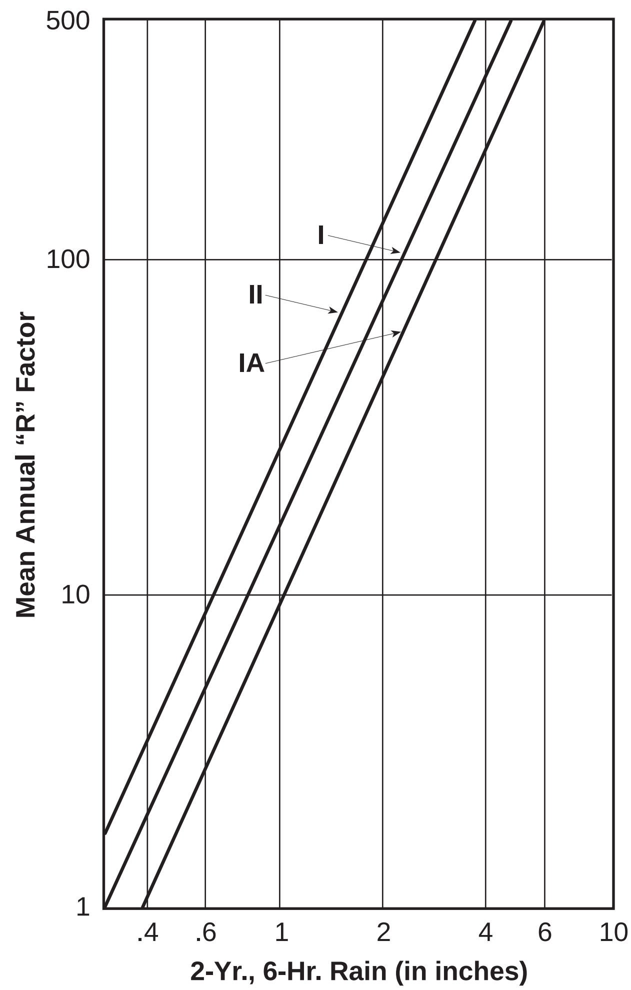
The K factor represents the potential erodibility a soil has based on its properties. The texture and gradation of the soil exposed during construction must be known or anticipated. In general, an engineer working on a new project may find soil properties from actual test results performed with the current project soils report. If a new soils report is not available, it is suggested the engineer review recent soils reports filed on the property or within the vicinity of the study area.

Table 5-2 provides a list of soil types, some of which are located in the San Diego Region. Once the soil classification is known, the engineer may use this list to find the K factor of the soil.

If specific soil characteristics of the soil are known or anticipated, there is another method to find the K factor by using the nomograph in Figure 5-4 (published by Wischmeier et al. 1965).

5.2.6.3 Slope Length and Steepness Factors (*L,s*)

The effect of length (*L*) and steepness (*s*) were established separately but are typically combined into a one single topographic factor. The combined Ls factor is graphed in Figure 5-5.

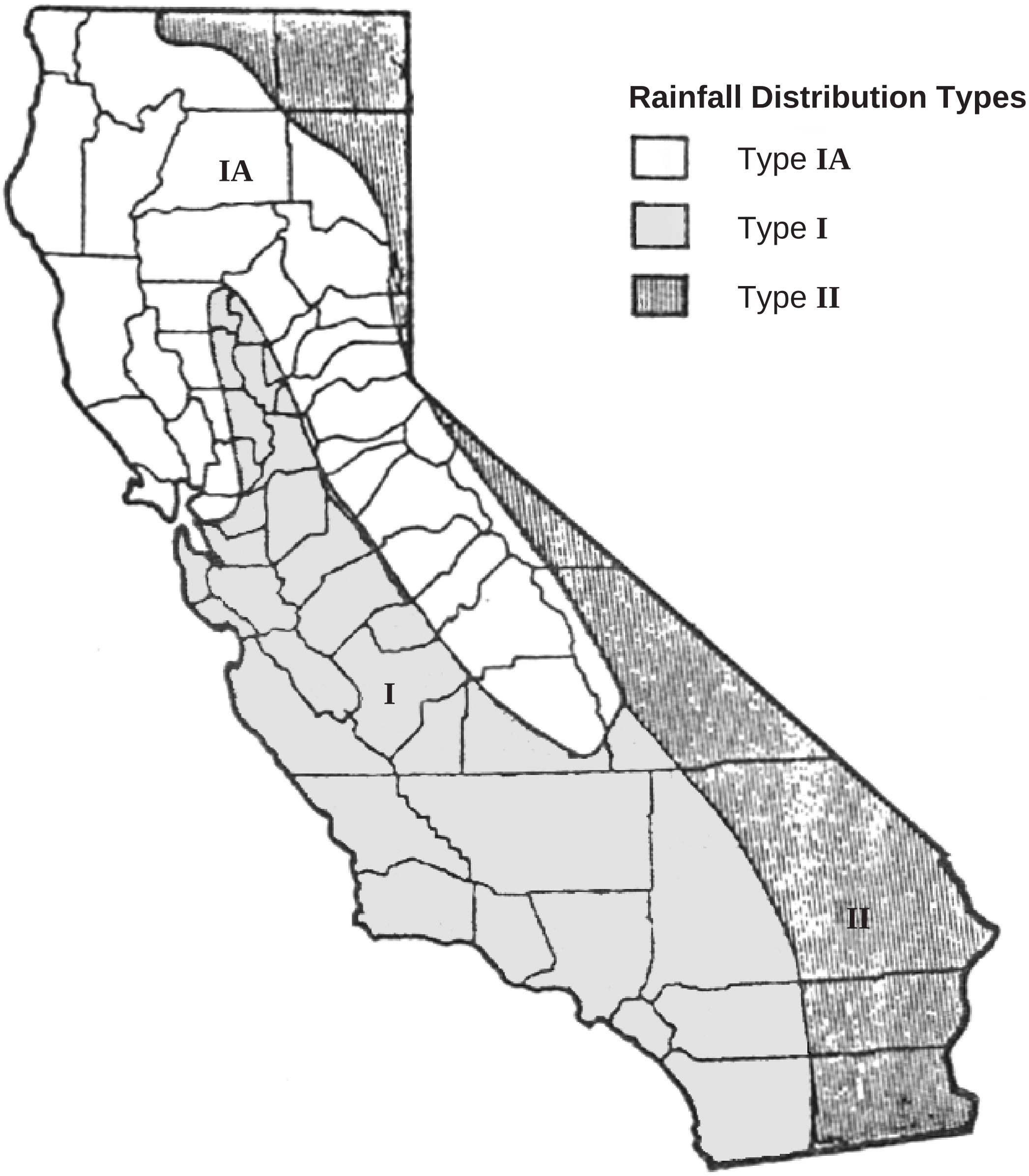


SOURCE: Wischmeier, 1977

R Factors based on 2-Year, 6-Hour Storm Event (Intensity)

FIGURE

5-2



SOURCE: Wischmeier, 1977

Rainfall Distribution Regions in California

FIGURE 5-3

Table 5-2

K FACTORS FOR SOILS IN THE SAN DIEGO REGION AND OTHERS

K factors for use within existing water erosion source areas
(using Universal Soil Loss Equation)

	MAPPING UNIT	K FACTOR
1.	Acid Igneous rockland (AcG)	*
2.	AtD (Altamount clay 9-15% slopes)	.24
	AtD2 (Altamount clay 9-15% slopes, eroded)	.24
	AtE (Altamount clay 15-30%)	.24
	AtE2 (Altamount clay 15-30%, eroded)	.24
	AtF (Altamount clay 30-50%)	.24
3.	AvC (Anderson very gravelly sandy loam 5-9% slopes)	0.15
	AvF (Anderson very gravelly sandy loam 9-45% slopes)	0.15
4.	AvC (Arlington coarse sandy loam 2-9% slopes)	0.17
5.	AwC (Auld clay 5-9% slopes)	.28
	AwD (Auld clay 9-15%)	.28
6.	AyE (Auld stoney clay 9-30%)	.24
7.	BaG (Badland)	*
8.	BbE (Bancas stony loam 5-30%)	.28
	BbE2 (Bancas stony loam 5-30% eroded)	.28
	BbG (Bancas stony loam 30-65%)	.28
	BbG2 (Bancas stony loam 30-65% eroded)	.28
9.	BeE (Blasingame loam 9-30%)	.37
10.	BgE (Blasingame stony loam 9-30%)	.32
	BgF (Blasingame stony loam 30-50%)	.32
11.	Bonsall (sandy loam 2-9% BlC)	.20
	BlC2 (Bonsall sandy loam 2-9% eroded)	.20
	BlD2 (Bonsall sandy loam 9-15% eroded)	.20
12.	BmC (Bonsall sandy loam thick surface 2-9%)	.20
13.	Bn9 (Bonsall-Fallbrook sandy loams 2-5%)	

Table 5-2 (Continued)

K FACTORS FOR SOILS IN THE SAN DIEGO REGION AND OTHERS

MAPPING UNIT		K FACTOR
14.	BoC (Boomer loam 2-9% slopes)	.37
	BoE (Boomer loam 9-30%)	.37
15.	BrE (Boomer stony loam 9-30%)	.32
	BrG (Boomer stony loam 30-65%)	.32
16.	BsC (Bosanko clay 2-9%)	.28
	BsD (Bosanko clay 9-15%)	.28
	BsE (Bosanko clay 15-30%)	.28
17.	BtC (Bosanko clay 5-9%)	N/A
18.	BuB (Bull Trail sandy loam 2-5%)	.28
	BuC (Bull Trail sandy loam 5-9%)	.28
	BuD2 (Bull Trail sandy loam 9-15% eroded)	.28
	BuE2 (Bull Trail 15-30% eroded)	.28
19.	CaB (Calpine coarse sandy loam 2-5%)	0.15
	CaC (Calpine coarse sandy loam 5-9%)	0.15
	CaC2 (Calpine coarse sandy loam 5-9% eroded)	.20
	CaD2 (Calpine coarse sandy loam 9-15% eroded)	.20
20.	CbB (Carlsbad gravelly loamy sand 2-5%)	.17
	CbC (Carlsbad gravelly loamy sand 5-9%)	.17
	CbD (Carlsbad gravelly loamy sand 9-15%)	.17
21.	CcC (Carlsbad-Urban land complex 2-9%)	*
	CcE (Carlsbad-Urban land complex 9-30%)	*
22.	CeC (Carrizo very gravelly sand 0-9%)	.10
23.	CfB (Chesterton fine sandy loam 2-5%)	.24
	CfC (Chesterton fine sandy loam 5-9%)	.24
	CfD2 (Chesterton fine sandy loam 9-15% eroded)	.24
24.	CgC (Chesterton-Urban land complex 2-9%)	*
25.	ChA (Chino fine sandy loam 0-2% slopes)	.24
	ChB (Chino fine sandy loam 2-5%)	.24

Table 5-2 (Continued)

K FACTORS FOR SOILS IN THE SAN DIEGO REGION AND OTHERS

MAPPING UNIT		K FACTOR
26.	CkA (Chino silt loam saline 0-2%)	.43
27.	ClD2 (coarse sandy loam 5-15%)	.24
	ClE2 (coarse sandy loam 15-30%)	.24
	ClG2 (coarse sandy loam 30-65%)	.24
28.	CmE2 (rocky coarse sandy loam 9-30%)	.24
29.	CmrG (very rocky coarse sandy loam 30-75%)	.20
30.	CnE2 (rocky sandy loam 9-30%)	*
	CnG2 (rocky sandy loam 30-65%)	*
31.	Co (clayey alluvial land)	.24
32.	Cr (coastal beaches)	*
33.	CsB (loamy sand 0-5%)	.20
	CsC (loamy sand 5-9%)	.20
	SsD (loamy sand 9-15%)	.20
34.	CtE (coarse sandy loam 5-30%)	.17
	CtF (coarse sandy loam 30-50%)	.17
35.	CuE (rocky coarse sandy loam 5-30%)	.15
	CuG (rocky coarse sandy loam 30-70%)	.15
36.	CuG (stony fine sandy loam 30-75%)	.15
37.	DaC (clay 2-9%)	.24
	DaD (clay 9-15%)	.24
	DaE (clay 15-30%)	.24
	DaE2 (clay 15-30%)	.24
	DaF (clay 30-50%)	.24
38.	DcD (urban land complex 5-15%)	*
	DcF (urban land complex 15-50%)	*
39.	DoE (urban land complex 9-30%)	*
40.	EdC (shaly fine sandy loam 2-9%)	.17

Table 5-2 (Continued)

K FACTORS FOR SOILS IN THE SAN DIEGO REGION AND OTHERS

MAPPING UNIT		K FACTOR
41.	EsC (very fine sandy loam 5-9%)	.43
	EsD2 (very fine sandy loam 9-15%)	.43
	EsE2 (very fine sandy loam 15-30%)	.43
	EvC (very fine sandy loam 5-9%)	.43
42.	ExE (rocky silt loam 9-30%)	.43
	ExG (rocky silt loam 30-70%)	.43
43.	FaB (sandy loam 2-5%)	.28
	FaC (sandy loam 5-9%)	.28
	FaC2 (sandy loam 5-9%)	.28
	FaD2 (sandy loam 9-15%)	.28
	FaE2 (sandy loam 15-30%)	.28
	FaE3 (sandy loam 9-30%)	.24
44.	FeC (rocky sandy loam 5-9%)	.24
	FeE (rocky sandy loam 9-30%)	.24
	FeE2 (rocky sandy loam 9-30%)	.24
45.	FvD (sandy loam 9-15%)	*
	FvE (sandy loam 15-30%)	*
46.	FwF (fine sandy loam 30-50%)	.32
47.	FxE (rocky fine sandy loam 9-30%)	.32
	FxG (rocky fine sandy loam 30-70%)	.32
48.	GaE (fine sandy loam 9-30%)	.43
	GaF (fine sandy loam 30-50%)	.43
49.	GoA (fine sandy loam 0-2%)	.20
50.	GrA (sandy loam 0-2%)	.24
	GrB (sandy loam 2-5%)	.24
	GrC (sandy loam 5-9%)	.24
	GrD (sandy loam 9-15%)	.24
51.	HaG (gravelly clay loam 30-75%)	.17

Table 5-2 (Continued)

K FACTORS FOR SOILS IN THE SAN DIEGO REGION AND OTHERS

MAPPING UNIT		K FACTOR
52.	HmD (fine sandy loam 5-15%)	.24
	HmE (fine sandy loam)	.24
53.	HnE (stony fine sandy loam 5-30%)	.20
	HnG (stony fine sandy loam 30-60%)	.20
54.	HoC (fine sandy loam, deep 2-9%)	.24
55.	HrC (loam 2-9%)	.37
	Hrc2 (loam 5-9%)	.37
	HrD (loam 9-15%)	.32
	HrE2 (loam 15-30%)	.32
56.	HuC (urban land complex 2-9%)	*
	HuE (urban land complex 9-30%)	*
57.	InA (silt loam 0-2%)	.55
	InB (silt loam 2-5%)	.55
	IoA (saline 0-2%)	.55
58.	IsA (silt loam, dark variant)	.49
59.	KcC (loamy coarse sand 5-9%)	.17
	KcD2 (loamy coarse sand 9-15%)	.17
60.	LaE2 (loamy coarse sand 5-30%)	.17
	LaE3 (loamy coarse sand 5-30%)	.17
61.	LcE (rocky loamy coarse sand 5-30%)	.15
	LcE2 (rocky loamy coarse sand 5-30%)	.15
	LcF2 (rocky loamy coarse sand 30-50%)	.15
62.	LdE (complex 9-30%)	*
	LdG (complex 30-65%)	*
63.	LeC (2-(%)	.17
	LeC2 (5-9%)	.17
	LeD (9-15%)	.17
	LeD2 (9-15%)	.17

Table 5-2 (Continued)

K FACTORS FOR SOILS IN THE SAN DIEGO REGION AND OTHERS

MAPPING UNIT		K FACTOR
	LeE (15-30%)	.17
	LeE2 (15-30%)	.15
	LeE3 (9-30%)	.15
64.	LfC (urban land complex 2-9%)	*
	LfE (urban land complex 9-30%)	*
65.	LpB (fine sandy loam 2-5%)	.28
	LpC (fine sandy loam 5-9%)	.28
	LpC2 (fine sandy loam 5-9%)	.28
	LpD2 (fine sandy loam 9-15%)	.28
	LpE2 (fine sandy loam 15-30%)	.28
66.	LrE (stony fine sandy loam 9-30%)	.24
	LrE2 (stony fine sandy loam 9-30%)	.24
	LrG (fine sandy loam 30-65%)	.24
67.	LsE (clay loam 9-30%)	.24
	LsF (clay loam 30-50%)	.24
68.	Lu (loamy alluvial land)	*
69.	LuF3 (loamy alluvial land - Huerhuro complex 9-50%)	*
70.	Md (made land)	*
71.	MlC (loamy coarse sand 2-9%)	.10
	MlE (loamy coarse sand 9-30%)	.10
72.	MnA (coarse sandy loam 0-2%)	.17
	MnB (coarse sandy loam 2-5%)	.17
73.	MdA (sandy loam 0-2%)	.17
74.	MpA2 (fine sandy loam 0-2%)	.20
75.	MrG (metamorphic rock land)	*
76.	MvA (loamy coarse sand 0-2%)	.24
	MvC (loamy coarse sand 2-9%)	.24
	MvD (loamy coarse sand 9-15%)	.24

Table 5-2 (Continued)

K FACTORS FOR SOILS IN THE SAN DIEGO REGION AND OTHERS

MAPPING UNIT		K FACTOR
	MxA (loamy coarse sand wet 9-2%)	.24
77.	OhC (cobbly loam 2-9%)	.28
	OhE (cobbly loam 9-30%)	.28
	OhF (cobbly loam 30-50%)	.28
78.	OkC (urban land complex 2-9%)	*
	OkE (urban land complex 9-30%)	*
79.	PeA (sandy loam 0-2%)	.32
	PeC (sandy loam 2-9%)	.32
	PeC2 (sandy loam 5-9%)	.32
	PeD2 (sandy loam 9-15%)	.32
	PfA (thick surface 0-2%)	.32
	PfC (thick surface 2-9%)	.32
80.	Py	*
81.	RaA (sandy loam 0-2%)	.32
	RaB (sandy loam 2-5%)	.32
	RaC (sandy loam 5-9%)	.32
	RaC2 (sandy loam 5-9%)	.32
	RaD2 (sandy loam 9-15%)	.32
82.	RcD (gravelly sandy loam 9-15%)	.32
	RcE (gravelly sandy loam 15-30%)	.32
83.	RdC (gravelly loam 2-9%)	.32
84.	ReE (cobbly loam 9-30%)	.28
	RfF (cobbly loam 15-50%)	.28
85.	RhC (urban land complex 2-9%)	*
	RhE (urban land complex 9-30%)	*
86.	RkA (fine sandy loam 0-2%)	.32
	RkB (fine sandy loam 2-5%)	.32
	RkC (fine sandy loam 5-9%)	.32

Table 5-2 (Continued)

K FACTORS FOR SOILS IN THE SAN DIEGO REGION AND OTHERS

MAPPING UNIT		K FACTOR
87.	Rm (riverwash)	*
88.	RoA (fine sand 0-2%)	.17
	RrC (fine sand 5-9%)	.17
89.	RsA (loamy coarse sand 0-2%)	.20
	RsC (loamy coarse sand 2-9%)	.20
	RsD (loamy coarse sand 9-15%)	.20
90.	(rough broken land)	*
91.	SbA (clay loam 0-2%)	.37
	SbC (clay loam 2-9%)	.37
92.	ScA (clay 0-2%)	.24
	ScB (clay 2-5%)	.24
93.	SmE (rocky silt loam 9-30%)	.43
94.	SnG (rocky silt loam 9-70%)	.43
95.	SpE2 (rocky fine sandy loam 9-30%)	.28
	SpG2 (rocky fine sandy loam 30-65%)	.28
96.	SrD (sloping gullied land)	*
97.	SsE (stony loamy sand 9-30%)	.15
98.	StG (steep gullied land)	*
99.	SuA (gravelly clay loam 0-2%)	.24
	SuB (gravelly clay loam 2-5%)	.24
100.	SvE (stony land)	*
101.	TeF (terrace escarpments)	*
102.	Tf (tidal flats)	*
103.	ToE2 (rocky coarse sandy loam 5-30%)	.24
	ToG (rocky coarse sandy loam 30-65%)	.24
104.	TuB (sand 0-5%)	.17
105.	Urban land	*

Table 5-2 (Continued)

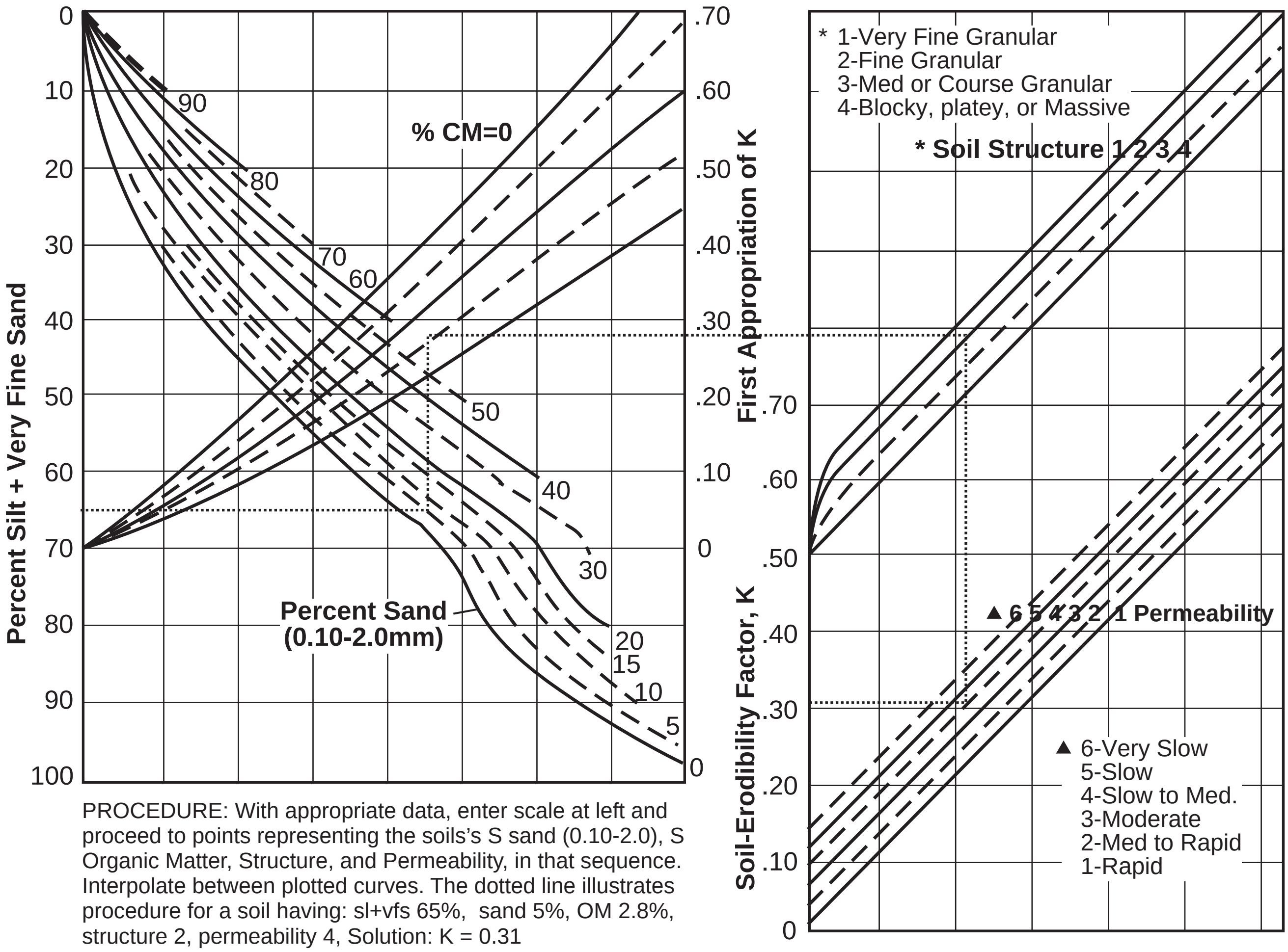
K FACTORS FOR SOILS IN THE SAN DIEGO REGION AND OTHERS

MAPPING UNIT		K FACTOR
106.	VaA (sandy loam 2-5%)	.28
	VaC (sandy loam 5-9%)	.28
	VaD (sandy loam 9-15%)	.28
107.	VbB (gravelly sandy loam 2-5%)	.28
	VbC (gravelly sandy loam 5-9%)	.28
108.	VsC (coarse sandy loam)	.28
	VsD (coarse sandy loam)	.28
	VsD2 (coarse sandy loam)	.28
	VsE (coarse sandy loam)	.28
	VsE2 (coarse sandy loam)	.28
	VsG (coarse sandy loam)	.28
109.	VvD (rocky coarse sandy loam 5-15%)	.28
	VvE (rocky coarse sandy loam 15-30%)	.28
	VvG (rocky coarse sandy loam 30-65%)	.28
110.	WmB (loam 2-5%)	.43
	WmC (loam 5-9%)	.43
	WmD (loam 9-15%)	.43

Footnotes:

*Too variable to determine

For complexes, use the individual soils within the complex to determine K



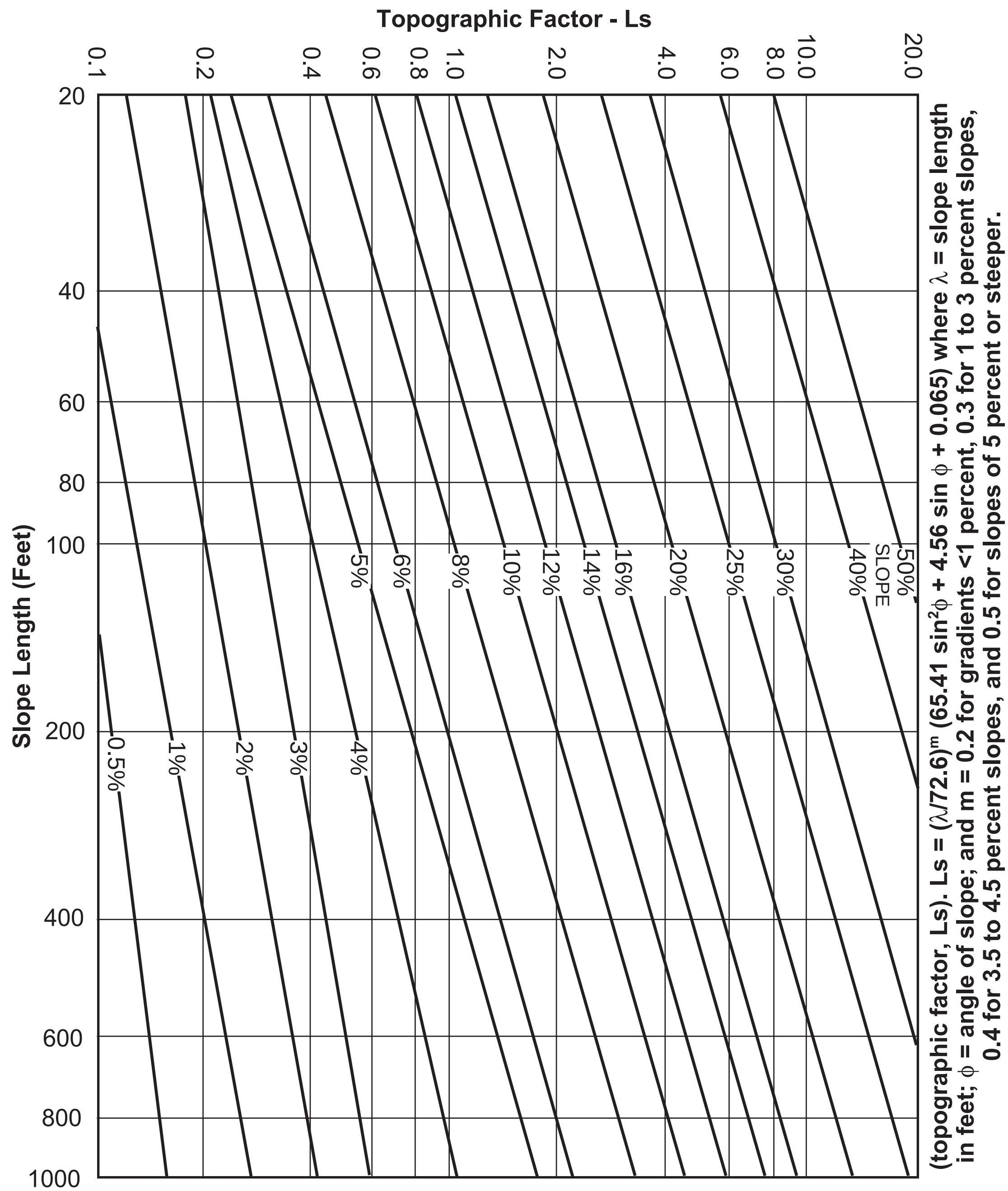
PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soils's S sand (0.10-2.0), S Organic Matter, Structure, and Permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: sl+vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4, Solution: K = 0.31

Where the silt fraction does not exceed 70 percent, the equation is 100 K=2.1 $M^{1.14}$ (10^{-4}) (12-a) + 3.25 (b-2) + 2.5 (c-3) where M= (percent sl + vfs) (100-percent c), a = percent organic matter, b = structure code, and c = profile permeability class.

SOURCE: SEA, USDA, Agricultural Handbook Number 537, December 1978

FIGURE 5-4

Nomograph for Soil Erodibility Factors



SOURCE: SEA, USDA, Agricultural Handbook Number 537, December 1978

FIGURE

5-5

Chart for determining Topographic Factors (L,s)

5.2.6.4 Cropping Management Factor (*C*)

The cropping management factor (*C*) represents the reduction in soil losses resulting from the effects of vegetation on a site. For complete, bare ground, the *C* factor is 1. As vegetation increases, the *C* factor value decreases to reflect the additional erosion protection. Please refer to the comprehensive list of *C* factors for permanent pasture, rangeland, and idle ground in Table 5-3. *C* factors for woodland are in Table 5-4. *C* factors for annual cover and various quantities of mulch are in Table 5-5. *C* factor and *P* factor values for rainfall erosion control measures are in Table 5-6 and *C* factors for established grass and ground cover are found in Figure 5-6.

5.2.6.5 Erosion Control Practice Factor (*P*)

This factor represents the reduction in soil losses resulting from the implementation of soil conservation measures. These measures may include but are not limited to contouring, terracing, or installing vegetation; mechanical devices; chemical devices; or combinations thereof. Standard *P* factor values can be found in Table 5-6.

5.2.6.6 Calculating Soil Loss (A_s)

Once all known factors of the USLE are identified, multiply them together and the result (A_s) will be the estimated soil loss per year for the site. The units of A_s will be in tons of soil (dry weight) per acre per year. To estimate volume of soil loss, convert A_s to weight, in pounds (use multiplier 2,000 pounds per 1 ton). Then calculate volume by dividing the weight (in pounds) by the density (pounds per cubic foot) of soil per the test results of the soils report. The final result will be the volume of estimated soil loss (in cubic feet).

Table 5-3

C FACTORS FOR PASTURE, RANGELAND, AND IDLE GROUND[1]

Vegetal Canopy			Cover That Contacts the Surface					
			Percent Ground Cover					
Type and Height of Raised Canopy[2]	Canopy Cover[3] %	Type[4]	0	20	40	60	80	95-100
Column No.:	2	3	4	5	6	7	8	9
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht.)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
		W	.17	.12	.09	.067	.038	.011
Appreciable brush or brushes (2 m fall ht.)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.041	.011
Trees but no appreciable low brush (4 m fall ht.)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

Source: Gray and Leiser 1982.

[1] All values shown assume (1) random distribution or mulch or vegetation, and (2) mulch of appreciable depth where it exists.
[2] Average fall height of waterdrops from canopy to soil surface: m = meters.
[3] Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).
[4] G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep.
W: Cover at surface is mostly broadleaf herbaceous plants (as weeds) with little lateral-root network near the surface, and/or undecayed residue.

Table 5-4

C FACTORS FOR WOODLAND

Stand Condition	Tree Canopy[1] % or Area	Forest Litter % of Area[2]	Undergrowth[3]	C Factor
Well Stocked	100-75	100-90	Managed[4] Unmanaged[4]	.001 .003-.011
Medium Stocked	70-40	85-75	Managed Unmanaged	.002-.004 .01-.04
Poorly Stocked	35-20	70-40[5]	Managed Unmanaged	.003-.009 .02-.09[5]

Source: USDA Soil Service 1978; Gray and Leiser 1982.

[1] When tree canopy is less than 20%, the area will be considered as grassland or cropland for estimating soil loss. See Table 5-3.
[2] Forest litter is assumed to be at least 2 inches deep over the percent ground surface area covered.
[3] Undergrowth is defined as shrubs, weeds, grasses, vines, etc., on the surface area not protected by forest litter. Usually found under canopy openings.
[4] Managed - grazing and fires are controlled.
Unmanaged - stands that are overgrazed or subjected to repeated burning.
[5] For unmanaged woodland with litter cover of less than 75%, C values should be derived by taking 0.7 of the appropriate values in Table 5-3. The factor of 0.7 adjusts for the much higher soil organic matter on permanent woodland.

Table 5-5

C FACTORS FOR ANNUAL COVER AND VARIOUS QUANTITIES OF MULCH[1]

Cover or Mulch	C Factor
bare areas	1.0
¼ ton straw mulch	0.52
½ ton straw mulch	0.35
¾ ton straw mulch	0.24
1 ton straw mulch	0.18
1½ ton straw mulch	0.10
2 tons straw mulch	0.06
3 tons straw mulch	0.03
4 tons straw mulch	0.02
annual cover	0.15

Source: USDA Soil Service 1978; Gray and Leiser 1982.

[1] When tree canopy is less than 20%, the area will be considered as grassland or cropland for estimating soil loss. See Table 5-3.

Table 5-6 (Page 1 of 2)

C FACTOR AND P FACTOR VALUES FOR RAINFALL EROSION CONTROL MEASURES

Treatment	C Factor	P Factor
BARE SOIL		
Packed and Smooth	1.00	1.00
Freshly Disked	1.00	0.90
Rough Irregular Surface	1.00	0.90
SEDIMENT BASIN/TRAP	1.00	0.50[A]
STRAW BALE BARRIER, GRAVEL FILTER, SAND BAGS	1.00	0.80
SILT FENCE BARRIER	1.00	0.50
ASPHALT/CONCRETE PAVEMENT	1.00	1.00
GRAVEL (¼" to 1½") @ 135 TONS/ACRE	0.05	1.00
SOD GRASS	0.01	1.00
TEMPORARY VEGETATION/COVER CROP	0.45[B]	1.00
HYDRAULIC MULCH @ 2 TONS/ACRE	0.10[C]	1.00
SOIL SEALANT	0.01 - 0.60[D]	1.00
EROSION CONTROL MATS/BLANKETS	0.10	1.00
HAY OR STRAW DRY MULCH @ 2 TONS/ACRE & ANCHORED		
Assumes planting of grass seed has occurred prior to application, otherwise C Factor = 1.00.		
Slope (%)		
1 to 10	0.06	1.00
11 to 15	0.07	1.00
16 to 20	0.11	1.00
21 to 25	0.14	1.00
25 to 33	0.17	1.00
> 33	0.20	1.00

Table 5-6 (Page 2 of 2)

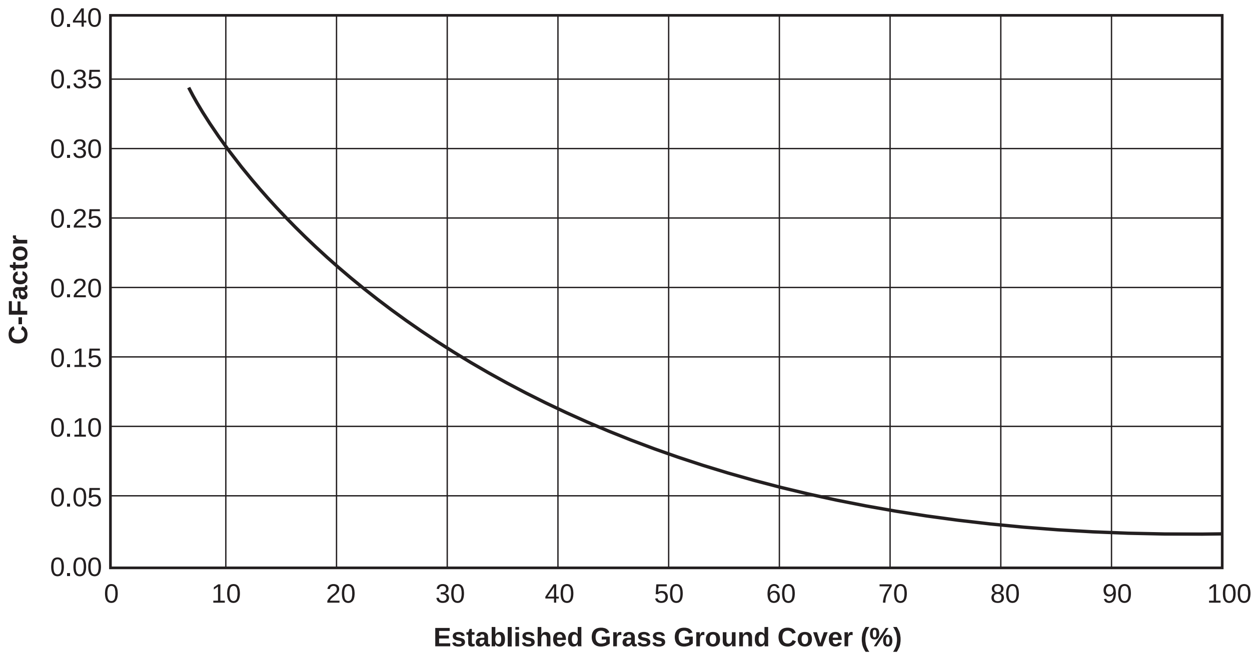
C FACTOR AND P FACTOR VALUES FOR RAINFALL EROSION CONTROL MEASURES

Treatment		C Factor	P Factor
CONTOUR FURROWED SURFACE			
Must be maintained throughout construction activities, otherwise P Factor = 1.00. Maximum length refers to down slope length.			
Slope (%)	Max. Length (feet)		
1 to 2	400	1.00	0.60
3 to 5	300	1.00	0.50
6 to 8	200	1.00	0.50
9 to 12	120	1.00	0.60
13 to 16	80	1.00	0.70
17 to 20	60	1.00	0.80
> 20	50	1.00	0.80
TERRACING			
Must contain 10-year runoff volumes without overflowing, otherwise P Factor = 1.00			
Slope (%)			
1 to 2		1.00	0.12
3 to 8		1.00	0.10
9 to 12		1.00	0.12
13 to 16		1.00	0.14
17 to 20		1.00	0.16
> 20		1.00	0.18
GRASS BUFFER STRIPS TO FILTER SEDIMENT LADEN SHEET FLOWS			
Strips must be at least 125 feet wide and have a ground cover value of 50% or greater, otherwise P Factor = 1.00.			
Basin Slope			
0% to 10%		1.00	0.60
10% to 24%		1.00	0.80

Source: IECA 1996.

NOTE: Use of C Factor or P Factor values other than reported in this table should be substantiated by documentation.

[A] Should be constructed as the first step in over lot grading
[B] Assumes planting occurs within optimal climatic conditions
[C] Some limitation on use in arid and semi-arid climates
[D] Value used must be substantiated by documentation



Ground cover represents the portion of total soil surface area occupied by grass when viewed from above.

SOURCE: IECA Conference, February 1996

FIGURE

5-6

C-Factors for Established Grass

5.3 SEDIMENTATION TRANSPORT

5.3.1 Natural Streambed

Soil particles are typically displaced by wind or water through the erosion process as previously described. Sedimentation transport is defined as soil particles moved from one location to another. During a rainstorm event (or inadvertent flooding, such as a water main break) erosion may take place on any area of exposed soil subjected to the sufficient water velocity and momentum of a watercourse. Erosion will usually occur in a watercourse (e.g., riverbed, ravine, stream, channel, or gully) when the velocity of water exceeds the weight and cohesion of the soil particle being displaced. Once displaced, the soil particle becomes suspended in the water for a period of time. The soil particle travels with the water and is eventually deposited downstream. The distance the soil particle will travel depends on many things, including the weight of the soil particle, volume and velocity of the water displacing it, storm duration, peak storm flow characteristics, topographic features of the watershed, and character of the watercourse.

Sedimentation transport is an event that has recurred throughout history, evidenced by beach sand brought from the tops of mountains. As sediments are displaced and transported downstream, typically there are other sediments to fill the remaining void (see Figure 5.7).

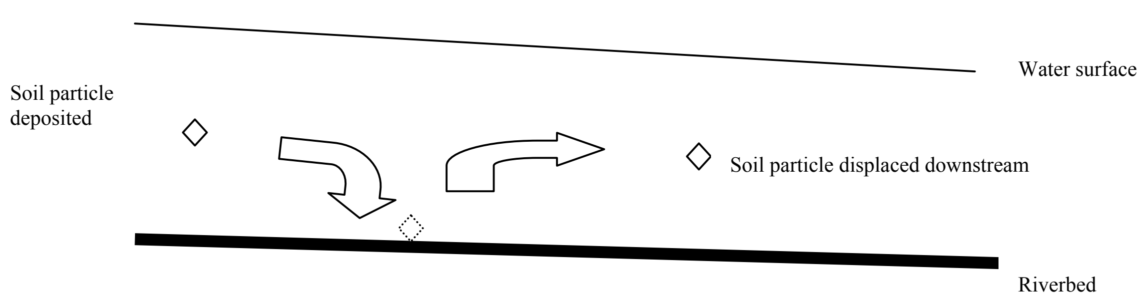


Figure 5-7
Sedimentation Transport

In general, most established watercourses have reached a relatively close equilibrium in which the displaced sediment is replaced by sediment displaced upstream. If the amount of upstream sediments is not enough to replace the downstream sediment volumes being transported, this will lead to lower channel bed elevations, better known as scour. Conversely, if the inflow of upstream sediments exceeds downstream sediment volumes, this will lead to increases in the channel bed elevations, better known as deposition. Thus, changes in sedimentation transport lead to changes in the channel bed elevations.

Channel bed elevations are important to any facility crossing a watercourse (e.g., bridge abutment, bridge piling, storm drain outlet, gas main, or sewer main). These facilities each require designs with assumed finished grade elevations. If a proposed facility crosses any major watercourse, an analysis must be prepared to predict anticipated changes in channel bed elevations/profiles. This information is critical to designing support structures of a bridge or verifying whether a buried facility will be exposed during severe storm events.

The combination of man-made infrastructures and increased development presents difficulties in forecasting how sediments are transported in natural channels. One example of how infrastructure influences sedimentation transport is the construction of a bridge in a riverbed. The bridge would act as a constriction, resulting in increased velocities and an increase in sediment transport. This condition is apparent in scoured bridge crossings where the foundations of bridge pilings are exposed. A worst-case scenario would be the construction of a dam, which virtually eliminates the transport of sediments from areas upstream of the dam. An example of the influence of development upon sedimentation transport is the development of an existing 15-acre scrub brush land into an industrial complex with large buildings, parking lots, streets, and storm drains. This project would no doubt result in increased storm runoff quantities due to increased imperviousness of the buildings, parking lots, and streets, and shorter time of concentration. If an area is studied just downstream of a new development, this increased storm runoff has a potential to transport a higher volume of sediments than before the project was constructed. These are the issues that must be confronted and resolved prior to construction.

As an engineer, you should consider the effect sedimentation transport may have on any existing or proposed facilities within your project area. Your efforts should also expand to consider the effect your project will have on downstream projects (off-site) with respect to sedimentation transport. The process of sedimentation transport contains many complexities and variables and is typically forecasted by computer models. A channel bed study should describe the watershed area and characteristics, study limits of the channel, channel characteristics, soil types, model chosen, results of water surface profiles and channel bed, and technical appendices.

5.3.2 Development

After a project has been constructed in urban development, the potential for erosion diminishes as buildings are erected, surfaces are paved or improved, underground storm drains are installed, average slopes are reduced, and vegetation is established. However, some projects include the construction of storm drain infrastructure that collects stormwater from off-site or on-site tributary areas that are still undeveloped. These areas may be developed in the future, or they may remain undeveloped if they are designated as open space by an agency. Some areas are subjected to fires that obliterate all vegetation. In any case, the engineer should consider the potential soil loss generated from areas like these. Storm drain infrastructure should be self-cleaning so that velocities are high enough to transport particles downstream.

An engineer should also design the storm drain to meet the standard service life of a public storm drain system. If sand or particles are suspended in the water, this will increase the water's ability to scour the surface of the storm drain. This scouring should be analyzed on proposed storm drains, especially those installed down steep slopes. Typically, in this situation the engineer would choose a thicker-walled concrete storm drain, or redesign the storm drain to reduce scouring velocities.

5.3.3 River Engineering

At times, a project may involve constructing improvements crossing creeks, streams, rivers, and other areas subject to floodwaters. These improvements may include but are not limited to streets, bridge abutments, bridge pilings, underground utilities, storm drain outlets, or flood control devices (e.g., weirs and flumes). These areas may be susceptible to changes in grades while sediment is transported downstream through what is called a fluvial process. A model is chosen to represent the study area and a series of calculations are performed. Typically, the engineer will submit a computer model due to the complexity of the calculations. The purpose of the calculations is to predict the maximum scour or deposition of soil along the channel bed. This prediction depends on channel characteristics, velocity of water, momentum of water, soil particle size, channel slope, and other criteria. As part of the design, the engineer must include sufficient theory and calculations to verify the improvements will endure anticipated changes in grades due to scour or soil deposition. It is recommended the owner/developer seek a professional engineer experienced in predicting changes in creeks, channels, or riverbeds to perform these models and calculations.

5.3.4 Supplemental References

The following are example references that may used to supplement the theory of sedimentation transport in channels:

(a) *Mechanics of Sedimentation Transportation and Alluvial Stream Problems,* *R.J. Garde.*

(b) *Fluvial Processes in River Engineering. Howard H. Chang, 1988.*

5.4 EROSION CONTROL

5.4.1 Introduction

If an engineer determines that a project has potential to generate certain quantities of sediments, the engineer should then make decisions about implementation of appropriate erosion control devices. The requirement to install erosion control is generally triggered by agency codes, ordinances, conditions of approval, agency grading permits, conditions of California Environmental Quality Act (CEQA) findings based on impacts, and (the latest) National Pollutant Discharge Elimination Permit requirements. Generally, during the grading plan review process, an agency will require the engineer to prepare erosion control plans to address the potential for erosion during construction of the project and the devices to be installed. With these plans, the contractor and agency inspector can ensure that sufficient erosion control devices are available year-round so the project can be secured in the event rainfall is forecasted or unexpectedly occurs. The owner, contractor, and agencies must ensure adequate erosion control devices are installed to prevent eroded material from exiting the site. The engineer should consult the appropriate local agency to determine acceptable best management practices (BMPs) for a project.

5.4.2 Erosion Control Devices

The purpose of erosion control devices is to capture or limit the anticipated erosion from a particular site for a design storm event. Each device has its own efficiency at capturing or limiting sedimentation yield. The engineer should choose the appropriate devices for each project. During construction phases of a project, the erosion control plan may require modifications due to unforeseen circumstances (e.g., intermediate topographic changes, availability of certain erosion control items, and unexpected rainstorms).

For a list of erosion control devices, please refer to the CalTrans Standards and website as these are the County's primary standards. This is a comprehensive list of erosion control devices that can be implemented during construction. The list also includes an explanation on each device, its purpose, and applicability. Please note there may be other devices that the industry may provide that are not covered in this handbook.

5.4.3 Erosion Control Plan

During design of grading plans, agencies may require the preparation of an erosion control plan. Erosion control plans are required year-round. The engineer should contact the agency to determine whether an erosion control plan should accompany the submittal. An erosion control plan is a guide for both the contractor and the agency inspector on how to protect the site and adjacent lands from erosion. However, the drainage characteristics of a site under construction will not be the same day to day. This is due to various grading operations, temporary excavations, temporary stockpiles, and so on. An erosion control plan cannot address every stage of the project. Although a difficult task, the engineer should try to determine most scenarios that will arise during construction and what methods the contractor can employ to ensure that stormwater erosion is controlled. A well-designed erosion control plan allows the contractor to order sufficient devices before the rainy season. The agency inspector can then verify that adequate devices are installed. If conditions arise on the site where the erosion control plan does not supply sufficient guidance to address a condition, the agency inspector may either offer guidance or require the engineer to provide the inspector and contractor with additional devices or measures to address the condition.

5.4.4 Maintenance of Erosion Control Devices

Once erosion control devices (temporary or permanent) are installed as part of a project, the captured eroded material should then be removed from the devices on a regular basis (typically after each rainfall event). This maintenance should be performed so that the efficiency of the devices is adequate to capture sediments from future rainfall events. Improper maintenance of erosion control devices can also lead to the deposition of sediments downstream causing damage to properties, building structures, storm drains, and vegetation, and possibly loss of life.

5.4.5 Maintenance of Storm Drain Infrastructure

Storm drains subject to sedimentation could fail in their function because of the following:

- decreased capacity to convey the stormwater they are designed to handle
- scour damage from the sediments in suspension
- pressure flows for which they are not designed
- “piping of soil” around the joints (which can lead to sink holes)

SECTION 6
RATIONAL METHOD HYDROGRAPH PROCEDURE

6.1 INTRODUCTION

The procedures in this section are for the development of hydrographs from RM study results for study areas up to approximately 1 square mile in size. The RM, discussed in Section 3, is a mathematical formula used to determine the maximum runoff rate from a given rainfall. It has particular application in urban storm drainage, where it is used to estimate peak runoff rates from small urban and rural watersheds for the design of storm drains and small drainage structures. However, in some instances such as for design of detention basins, the peak runoff rate is insufficient information for the design, and a hydrograph is needed. Unlike the NRCS hydrologic method (discussed in Section 4), the RM itself does not create hydrographs. The procedures for detention basin design based on RM study results were first developed as part of the East Otay Mesa Drainage Study. Rick Engineering Company performed this study under the direction of County Flood Control. The procedures in this section may be used for the development of hydrographs from RM study results for study areas up to approximately 1 square mile in size.

6.2 HYDROGRAPH DEVELOPMENT

The concept of this hydrograph procedure is based on the RM formula:

$$Q = C\ I\ A$$

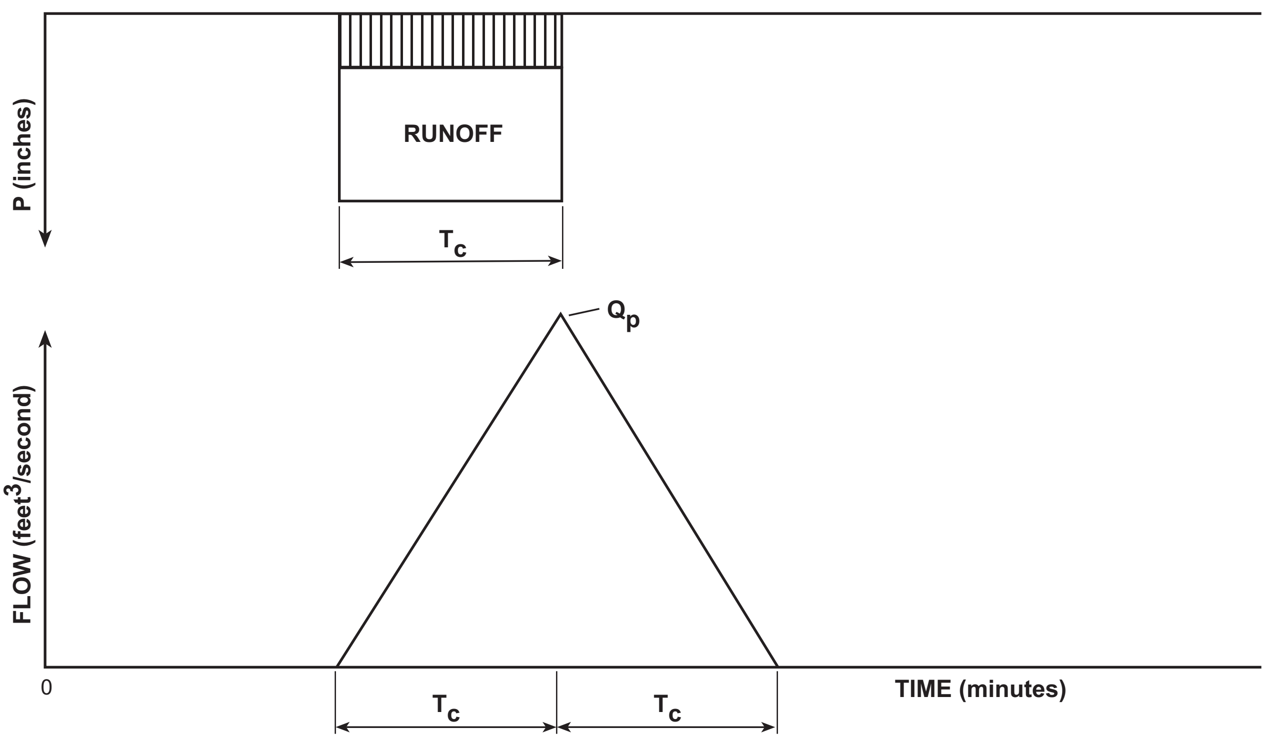
Where:
- Q = peak discharge, in cubic feet per second (cfs)
- C = runoff coefficient, proportion of the rainfall that runs off the surface (no units)
- I = average rainfall intensity for a duration equal to the T_c for the area, in inches per hour
- A = drainage area contributing to the design location, in acres

The RM formula is discussed in more detail in Section 3.

An assumption of the RM is that discharge increases linearly over the T_c for the drainage area until reaching the peak discharge as defined by the RM formula, and then decreases linearly. A linear hydrograph can be developed for the peak flow occurring over the T_c as shown in Figure 6-1. However, for designs that are dependent on the total storm volume, it is not sufficient to consider a single hydrograph for peak flow occurring over the T_c at the beginning of a 6-hour storm event because the hydrograph does not account for the entire volume of runoff from the storm event. The volume under the hydrograph shown in Figure 6-1 is equal to the rainfall intensity multiplied by the duration for which that intensity occurs (T_c), the drainage area (A) contributing to the design location, and the runoff coefficient (C) for the drainage area. For designs that are dependent on the total storm volume, a hydrograph must be generated to account for the entire volume of runoff from the 6-hour storm event. The hydrograph for the entire 6-hour storm event is generated by creating a rainfall distribution consisting of blocks of rain, creating an incremental hydrograph for each block of rain, and adding the hydrographs from each block of rain. This process creates a hydrograph that contains runoff from all the blocks of rain and accounts for the entire volume of runoff from the 6-hour storm event. The total volume under the resulting hydrograph is equal to the following equation:

$$VOL = CP_6A \qquad \text{(Eq. 6-1)}$$

Where: VOL = volume of runoff (acre-inches)
P_6 = 6-hour rainfall (inches)
C = runoff coefficient
A = area of the watershed (acres)



Triangular Hydrograph

FIGURE

6-1

6.2.1 Rainfall Distribution

Figure 6-2 shows a 6-hour rainfall distribution consisting of blocks of rain over increments of time equal to T_c. The number of blocks is determined by rounding T_c to the nearest whole number of minutes, dividing 360 minutes (6 hours) by T_c, and rounding again to the nearest whole number. The blocks are distributed using a (2/3, 1/3) distribution in which the peak rainfall block is placed at the 4-hour time within the 6-hour rainfall duration. The additional blocks are distributed in a sequence alternating two blocks to the left and one block to the right of the 4-hour time (see Figure 6-2). The total amount of rainfall ($P_{T(N)}$) for any given block (N) is determined as follows:

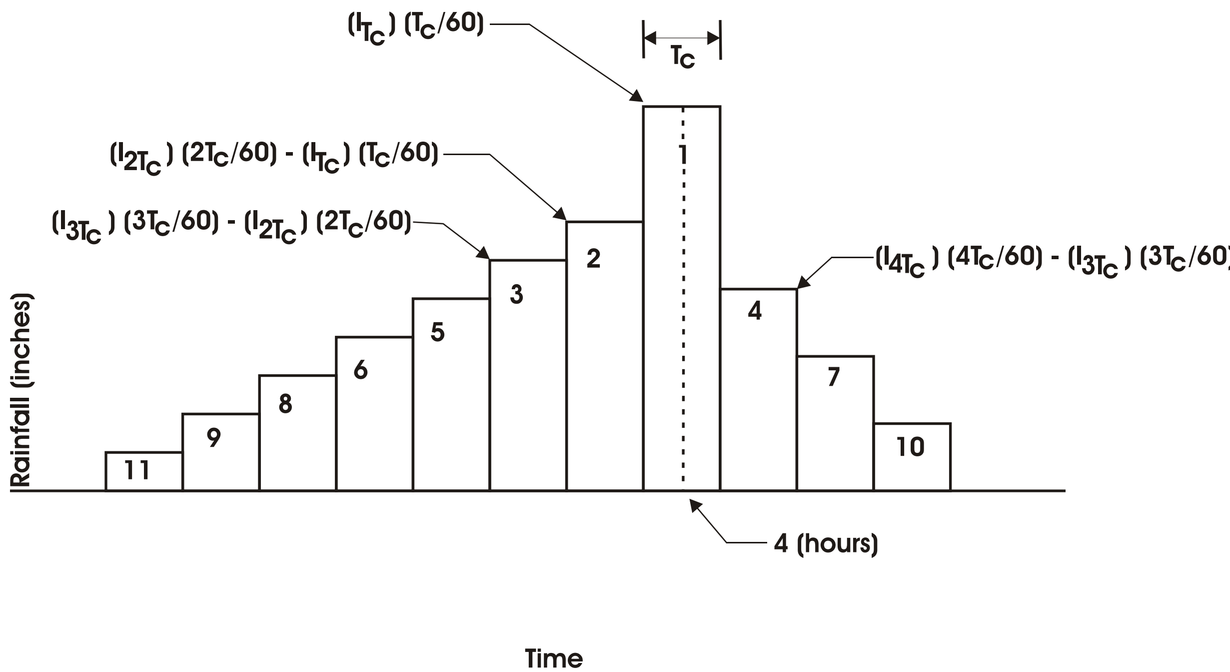
$$P_{T(N)} = (I_{T(N)}\ T_{T(N)}) / 60$$

Where: $P_{T(N)}$ = total amount of rainfall for any given block (N)
$I_{T(N)}$ = average rainfall intensity for a duration equal to $T_{T(N)}$ in inches per hour
$T_{T(N)}$ = NT_c in minutes (N is an integer representing the given block number of rainfall)

Intensity is calculated using the following equation (described in detail in Section 3):

$$I = 7.44\ P_6\ D^{-0.645}$$

Where: I = average rainfall intensity for a duration equal to D in inches per hour
P_6 = adjusted 6-hour storm rainfall
D = duration in minutes



FIGURE

Rainfall Distribution

6-2

Substituting the equation for I in the equation above for $P_{T(N)}$ and setting the duration (D) equal to $T_{T(N)}$ yields:

$$P_{T(N)} = [(7.44\ P_6/T_{T(N)}^{0.645})(T_{T(N)})] / 60$$
$$P_{T(N)} = 0.124\ P_6 T_{T(N)}^{0.355}$$

Substituting NT_c for T_T (where N equals the block number of rainfall) in the equation above yields:

$$P_{T(N)} = 0.124\ P_6\ (NT_c)^{0.355} \qquad \text{(Eq. 6-2)}$$

Equation 6-2 represents the total rainfall amount for a rainfall block with a time base equal to $T_{T(N)}$ (NT_c). The actual time base of each rainfall block in the rainfall distribution is T_c, as shown in Figure 6-2. The actual rainfall amount (P_N) for each block of rain is equal to P_T at N ($P_{T(N)}$) minus the previous P_T at N–1 ($P_{T(N-1)}$) at any given multiple of T_c (any NT_c). For example, the rainfall for block 2 is equal to $P_{T(N)}$ at $T_{T(N)} = 2T_c$ minus the $P_{T(N)}$ at $T_{T(N)} = 1T_c$, and the rainfall for block 3 equals $P_{T(N)}$ at $T_{T(N)} = 3T_c$ minus the $P_{T(N)}$ at $T_{T(N)} = 2T_c$, or P_N can be represented by the following equation:

$$P_N = P_{T(N)} - P_{T(N-1)} \qquad \text{(Eq. 6-3)}$$

For the rainfall distribution, the rainfall at block N = 1, ($1T_c$), is centered at 4 hours, the rainfall at block N = 2, ($2T_c$), is centered at 4 hours – $1T_c$, the rainfall at block N = 3, ($3T_c$), is centered at 4 hours – $2T_c$, and the rainfall at at block N = 4, ($4T_c$), is centered at 4 hours + $1T_c$. The sequence continues alternating two blocks to the left and one block to the right (see Figure 6-2).

6.2.2 Construction of Incremental Hydrographs

Figure 6-1 shows the relationship of a single block of rain to a single hydrograph. Figure 6-3 shows the relationship of the rainfall distribution to the overall hydrograph for the storm event. The peak flow amount from each block of rain is determined by the RM formula, Q = CIA, where I equals I_N (the actual rainfall intensity for the rainfall block). I_N is determined by dividing P_N by the actual time base of the block, T_c. The following equation shows this relationship:

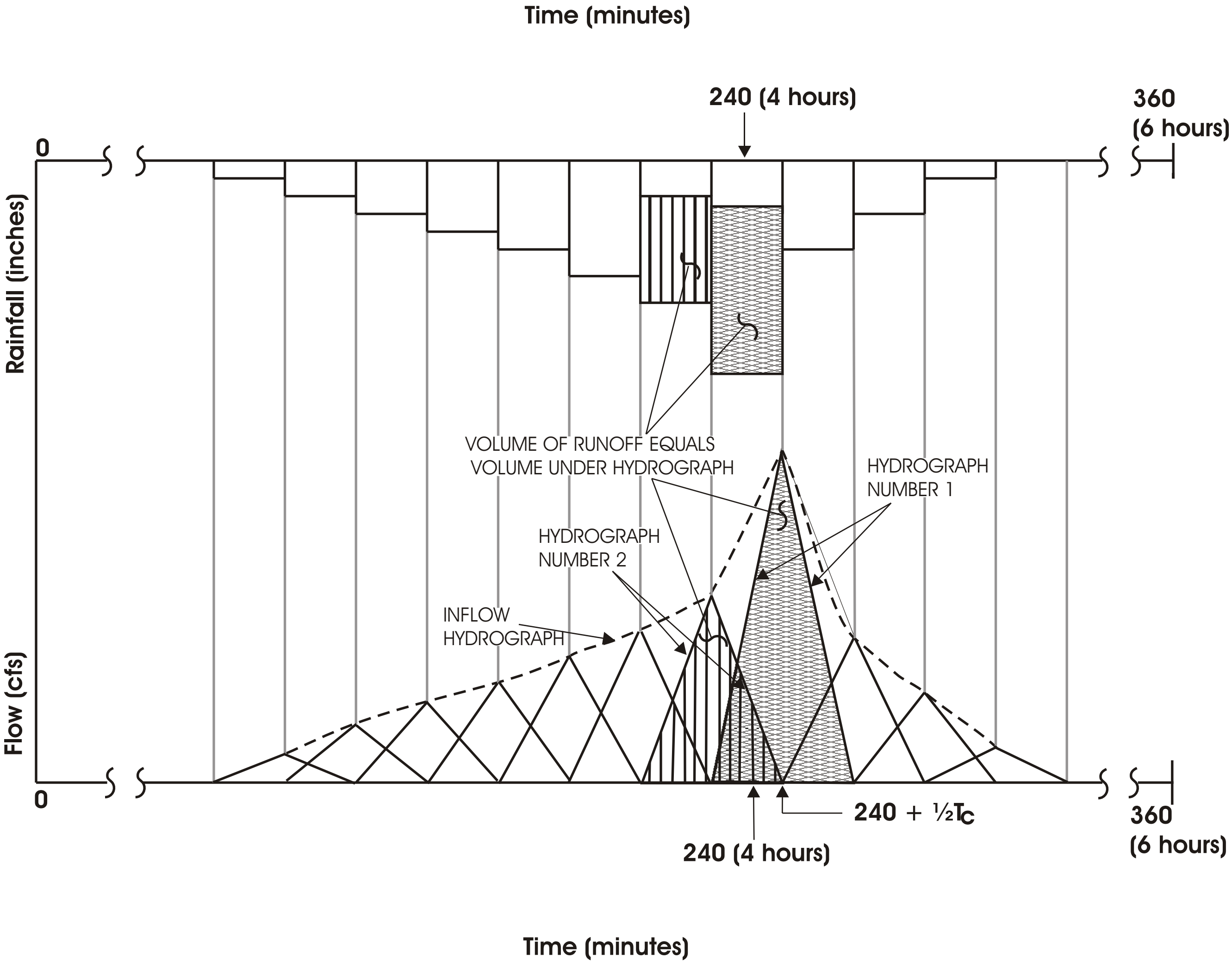
$$I_N = 60\ P_N/T_c \qquad \text{(Eq. 6-4)}$$

Where: I_N = average rainfall intensity for a duration equal to T_c in inches per hour
P_N = rainfall amount for the block in inches
T_c = time of concentration in minutes

By substituting equation 6-4 into the rational equation, the following relationship is obtained:

$$Q_N = 60\ CAP_N/T_c\ \text{(cfs)} \qquad \text{(Eq. 6-5)}$$

Finally, the overall hydrograph for the storm event is determined by adding all the hydrographs from each block of rain. Since the peak flow amount for each incremental hydrograph corresponds to a zero flow amount from the previous and proceeding hydrographs, as shown in Figure 6-3, the inflow hydrograph can be plotted by connecting the peak flow amounts (see the dashed line in Figure 6-3).



6-Hour Rational Method Hydrograph

FIGURE

6-3

6.3 GENERATING A HYDROGRAPH USING RATHYDRO

The rainfall distribution and related hydrographs can be developed using the RATHYDRO computer program provided to the County by Rick Engineering Company. A copy of this program is available at no cost from the County. The output from this computer program may be used with HEC-1 or other software for routing purposes.

The design storm pattern used by the RATHYDRO program is based on the (2/3, 1/3) distribution described in Sections 4.1.1 and 6.2.1. The ordinates on the hydrograph are calculated based on the County of San Diego Intensity-Duration Design Chart (Figure 3-1), which uses the intensity equation described in Sections 3.1.3 and 6.2.1 to relate the intensity (I) of the storm to T_c, $I = 7.44\ P_6 D^{-0.645}$. The computer program uses equations 6-2 and 6-3 described above and calculates I_N directly. The intensity at any given multiple of T_c is calculated by the following equation:

$$I_N = [(I_{T(N)})\ (T_{T(N)}) - (I_{T(N-1)})\ (T_{T(N-1)})]\ /\ T_c \qquad \text{(Eq. 6-6)}$$

Where: N = number of rainfall blocks
$T_{T(N)}$ = time of concentration at rainfall block N in minutes (equal to NT_c)
I_N = actual rainfall intensity at rainfall block N in inches per hour
$I_{T(N)}$ = rainfall intensity at time of concentration $T_{T(N)}$ in inches per hour

Figure 6-2 shows the rainfall distribution used in the RM hydrograph, computed at multiples of T_c. The rainfall at block N = 1, ($1T_c$), is centered at 4 hours, the rainfall at block N = 2, ($2T_c$), is centered at 4 hours – $1T_c$, the rainfall at block N = 3, ($3T_c$), is centered at 4 hours – $2T_c$, and the rainfall at at block N = 4, ($4T_c$), is centered at 4 hours + $1T_c$. The sequence continues alternating two blocks to the left and one block to the right (see Figure 6-2).

As described in Section 6.2.2, the peak discharge (Q_N) of the hydrograph for any given rainfall block (N) is determined by the RM formula Q = CIA, where $I = I_N$ = the actual rainfall intensity for the rainfall block. The RATHYDRO program substitutes equation 6-6 into the RM formula to determine Q_N yielding the following equation:

$$Q_N = [(I_{T(N)})\,(T_{T(N)}) - (I_{T(N-1)})\,(T_{T(N-1)})]\ CA / T_c \qquad \text{(Eq. 6-7)}$$

Where: Q_N = peak discharge for rainfall block N in cubic feet per second (cfs)
N = number of rainfall blocks
$T_{T(N)}$ = time of concentration at rainfall block N in minutes (equal to NT_c)
$I_{T(N)}$ = rainfall intensity at time of concentration $T_{T(N)}$ in inches per hour
C = RM runoff coefficient
A = area of the watershed (acres)

To develop the hydrograph for the 6-hour design storm, a series of triangular hydrographs with ordinates at multiples of the given T_c are created and added to create the hydrograph. This hydrograph has its peak at 4 hours plus ½ of the T_c. The total volume under the hydrograph is equal to the following equation (equation 6-1):

$$VOL = CP_6A$$

Where: VOL = volume of runoff (acre-inches)
P_6 = 6-hour rainfall (inches)
C = runoff coefficient
A = area of the watershed (acres)

SECTION 7
WATER QUALITY CONSIDERATIONS

Stormwater quality has increasingly become an integral aspect of stormwater management. As of the date of adoption for this Manual, policies are being formulated and revised. Inclusion of uniform stormwater quality procedures and policies in this Manual is premature until standards and criteria have been established, but the reader is advised to consult the current information available regarding methodologies and design criteria.

Several criteria for calculating treatment volume of runoff for volume-based BMPs or treatment flow rate of runoff for flow-based BMPs are based on the 85th percentile storm event. An 85th Percentile Precipitation Isopluvial Map for San Diego County was prepared by the County of San Diego and is provided in Appendix E. Because water quality policies and procedures vary greatly from region to region and from year to year, the reader is cautioned to confirm with the appropriate governing municipality that numeric sizing criteria based on the 85th percentile storm event are acceptable for sizing BMPs before referencing this map in the BMP design.

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SECTION 8
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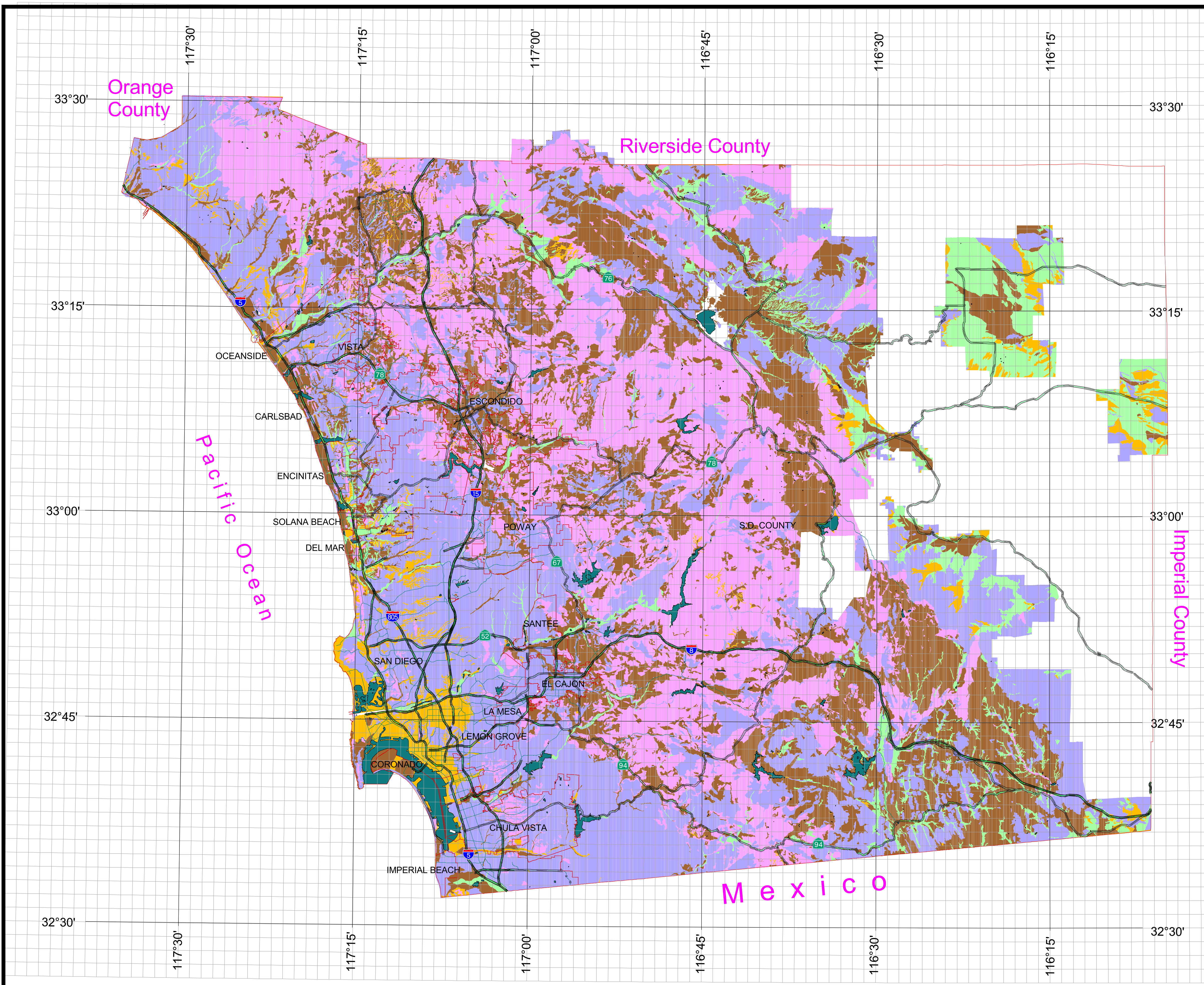
APPENDIX A

HYDROLOGIC SOIL GROUPS MAP



County of San Diego Hydrology Manual

Soil Hydrologic Groups

Legend

Soil Groups

- Group A
- Group B
- Group C
- Group D
- Undetermined
- Data Unavailable

DPW GIS
Department of Public Works
Geographic Information Services

SanGIS
We Have San Diego Covered!

N
W E
S

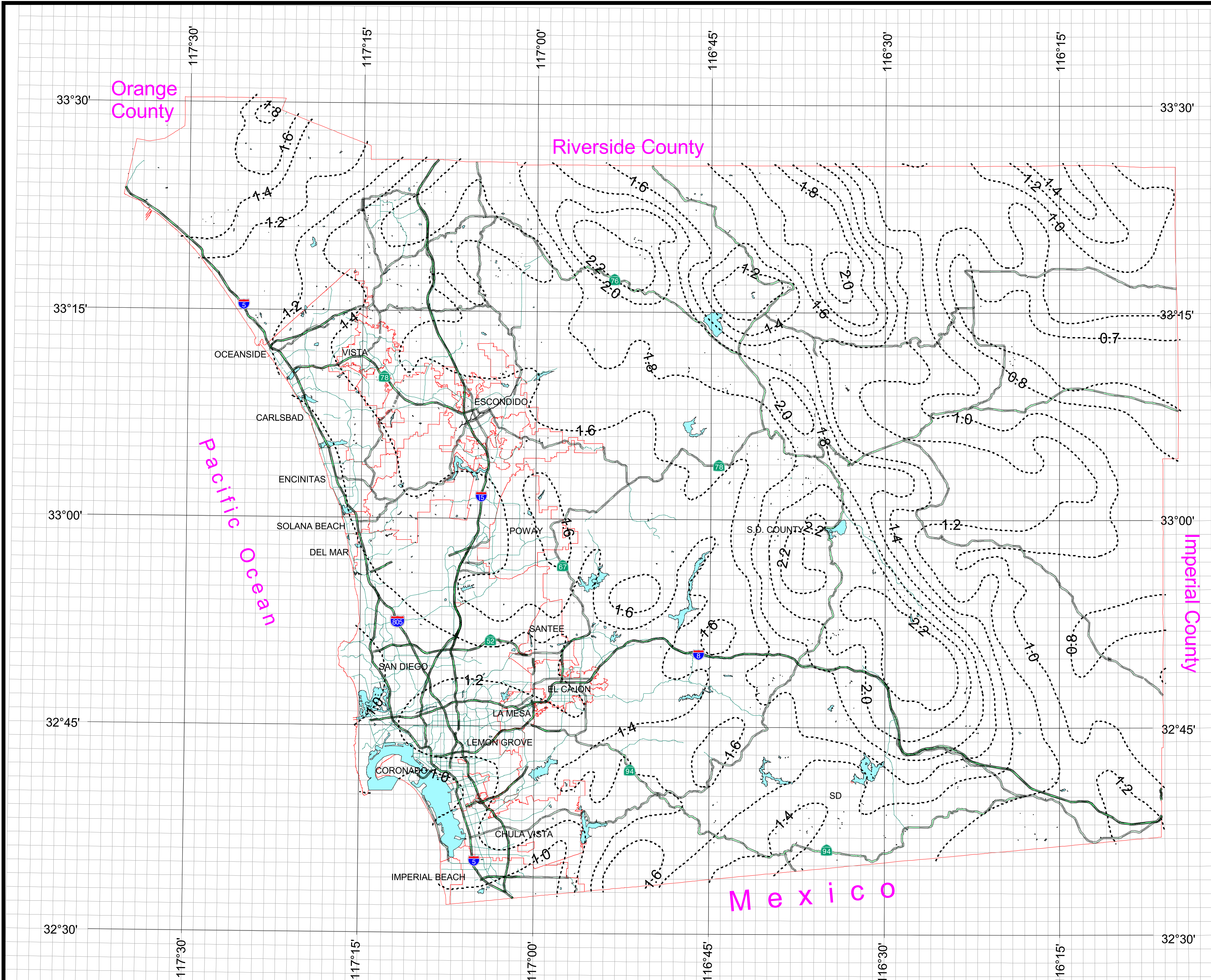
3 0 3 Miles

APPENDIX B

ISOPLUVIAL MAPS

County of San Diego Hydrology Manual

Rainfall Isopluvials



2 Year Rainfall Event - 6 Hours

Isopluvial (inches)

N E S W

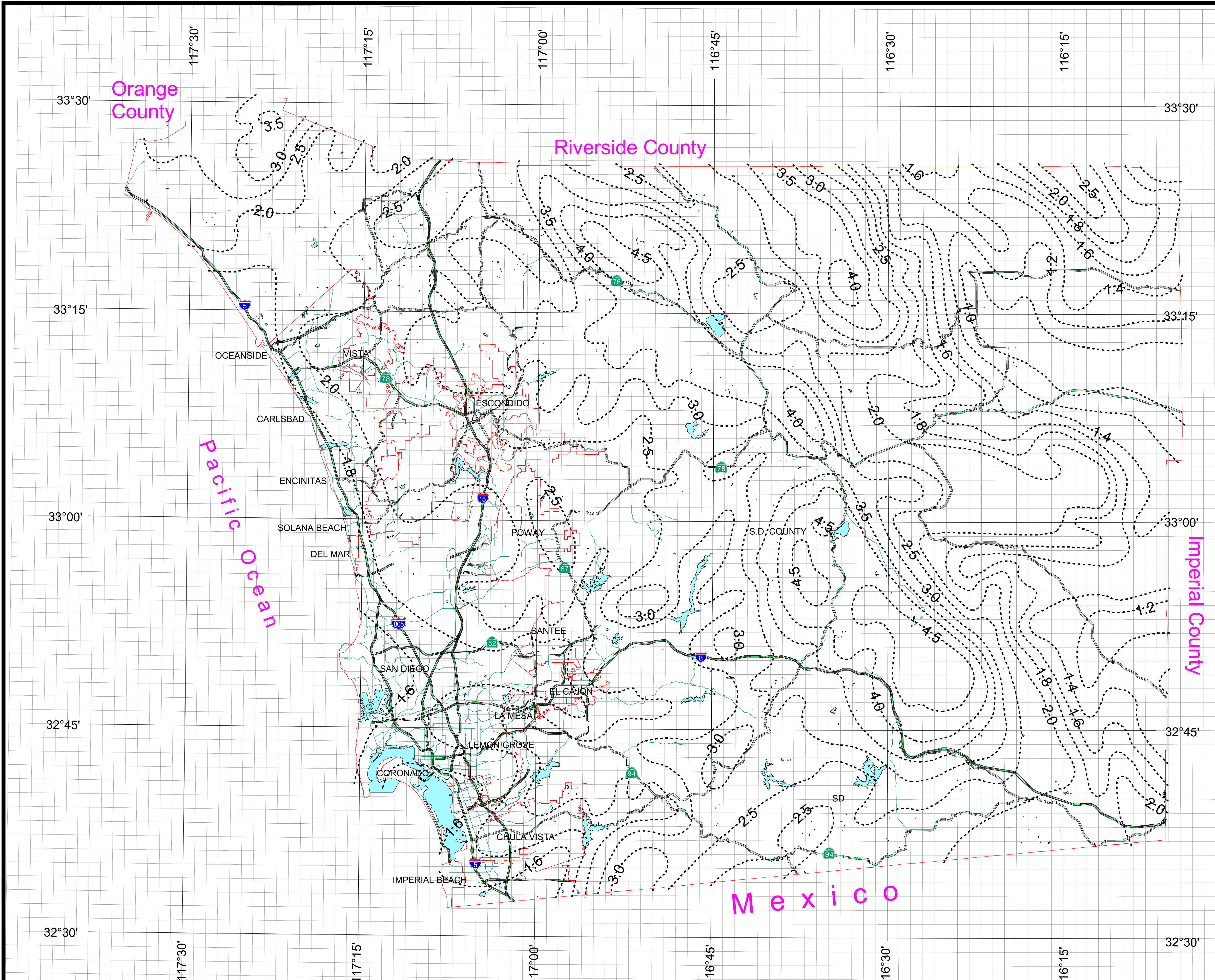
3 0 3 Miles

County of San Diego Hydrology Manual

Rainfall Isopluvials

2 Year Rainfall Event - 24 Hours

Isopluvial (inches)



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W E
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3 0 3 Miles

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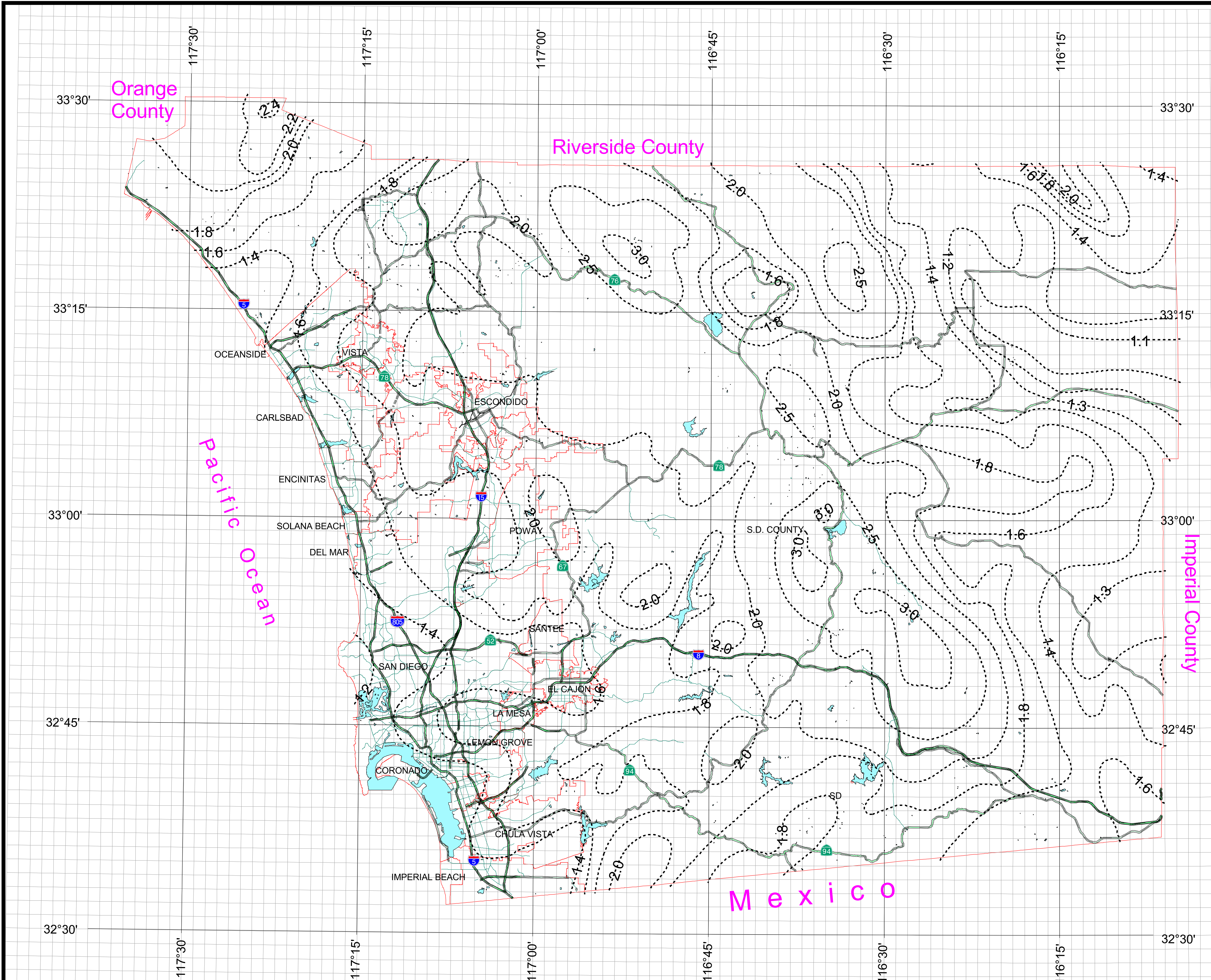
Rainfall Isopluvials



5 Year Rainfall Event - 6 Hours

Isopluvial (inches)

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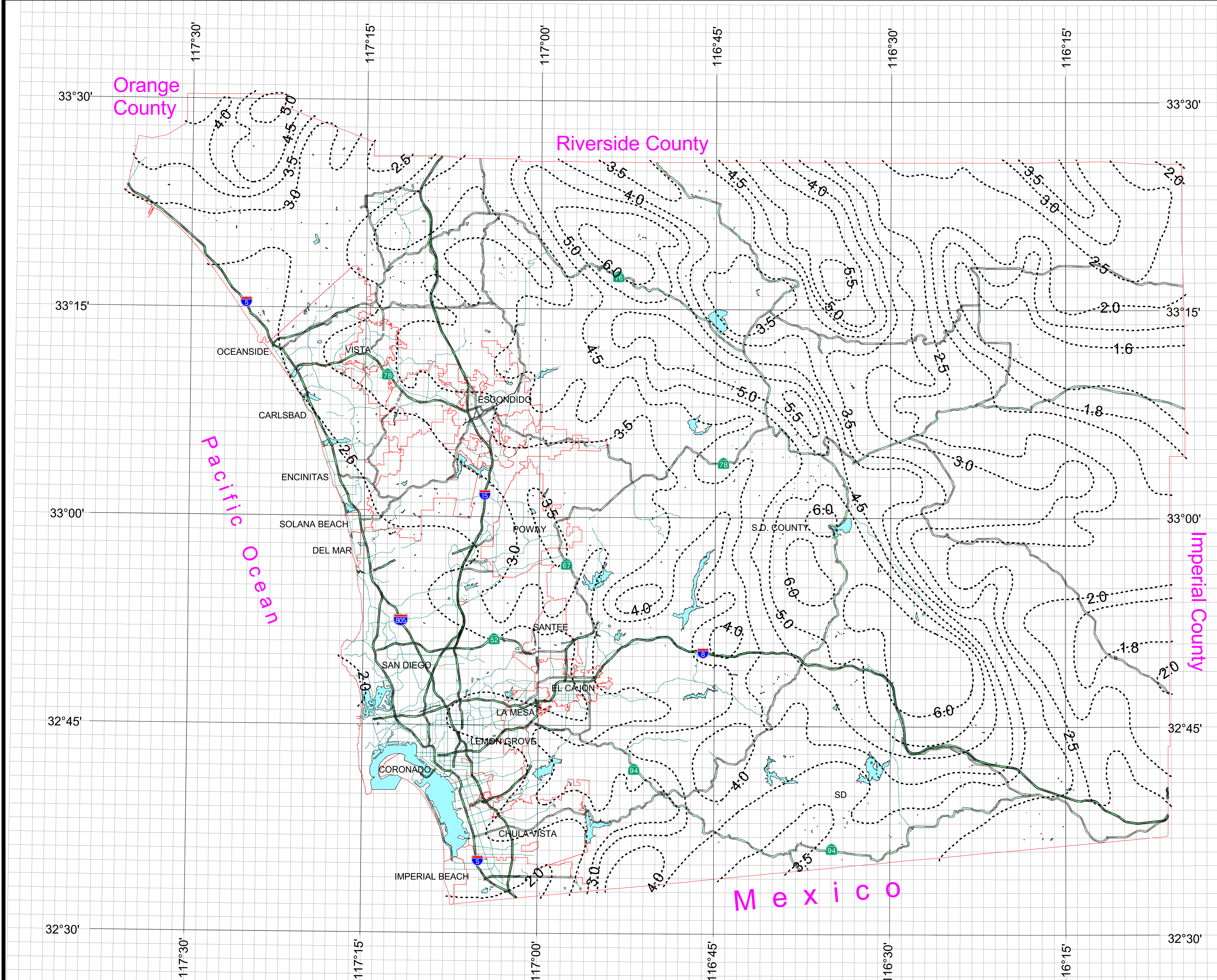
Rainfall Isopluvials

5 Year Rainfall Event - 24 Hours



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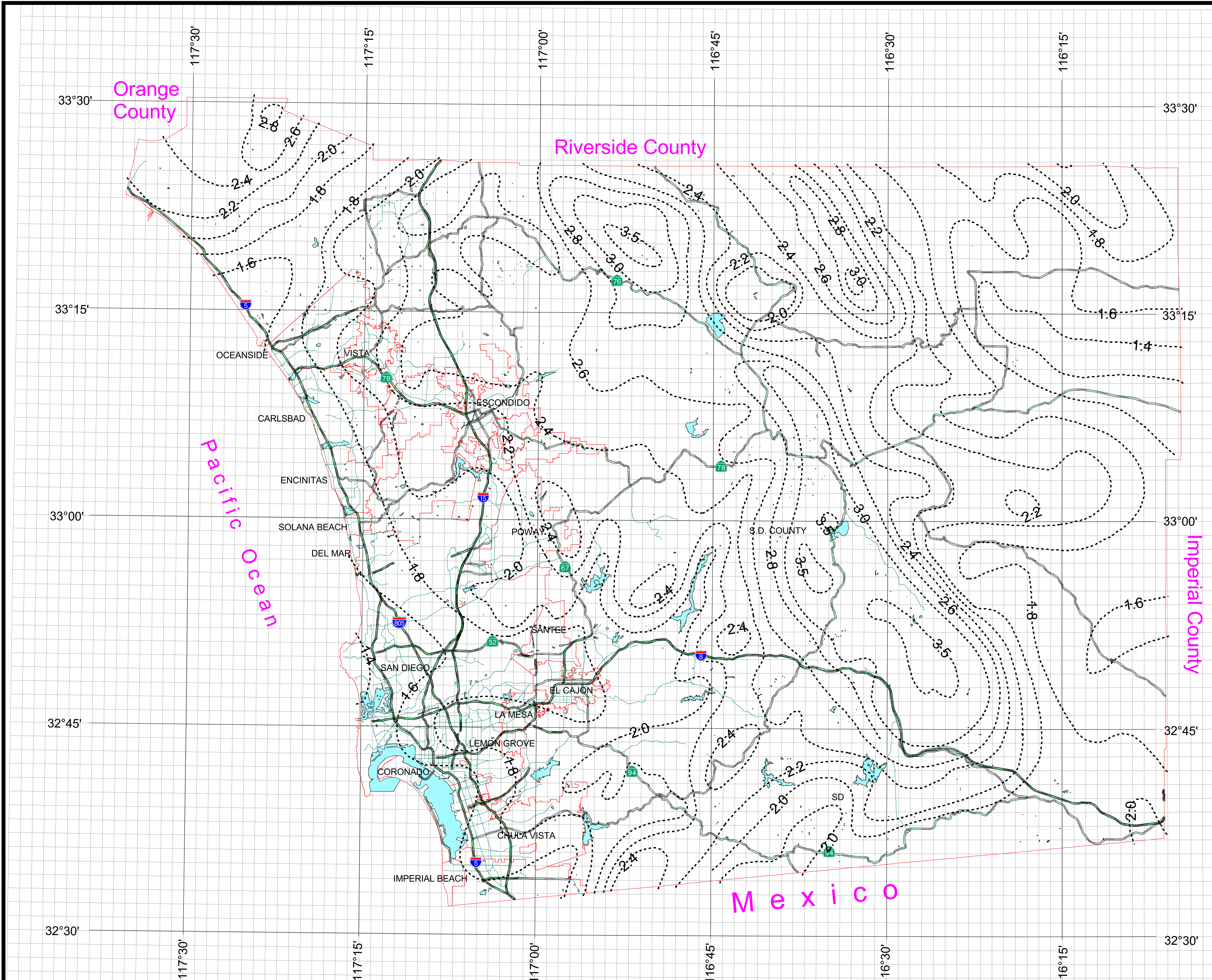
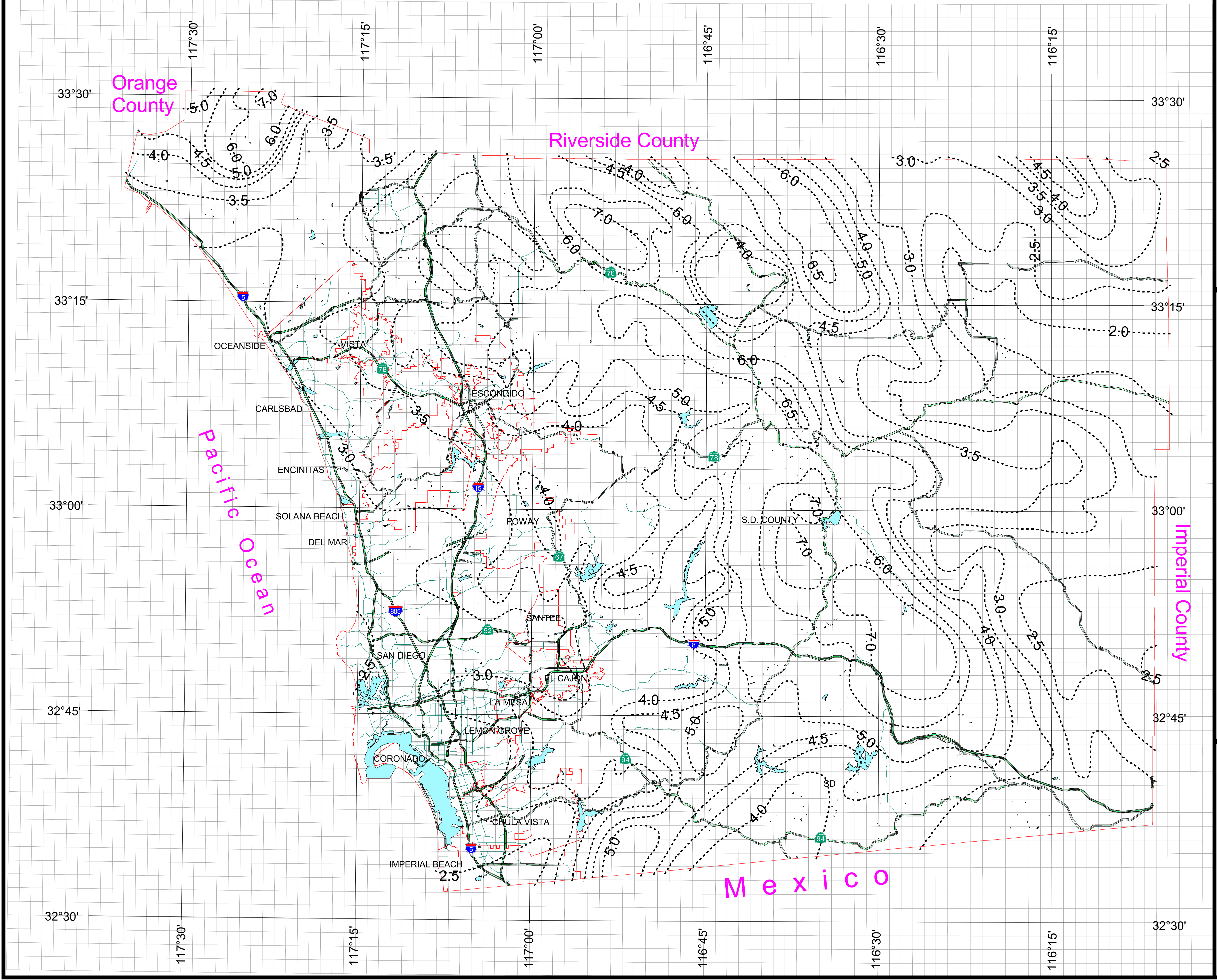


10 Year Rainfall Event - 6 Hours

Isopluvial (inches)

3 0 3 Miles



County of San Diego Hydrology Manual

Rainfall Isopluvials

10 Year Rainfall Event - 24 Hours

Isopluvial (inches)

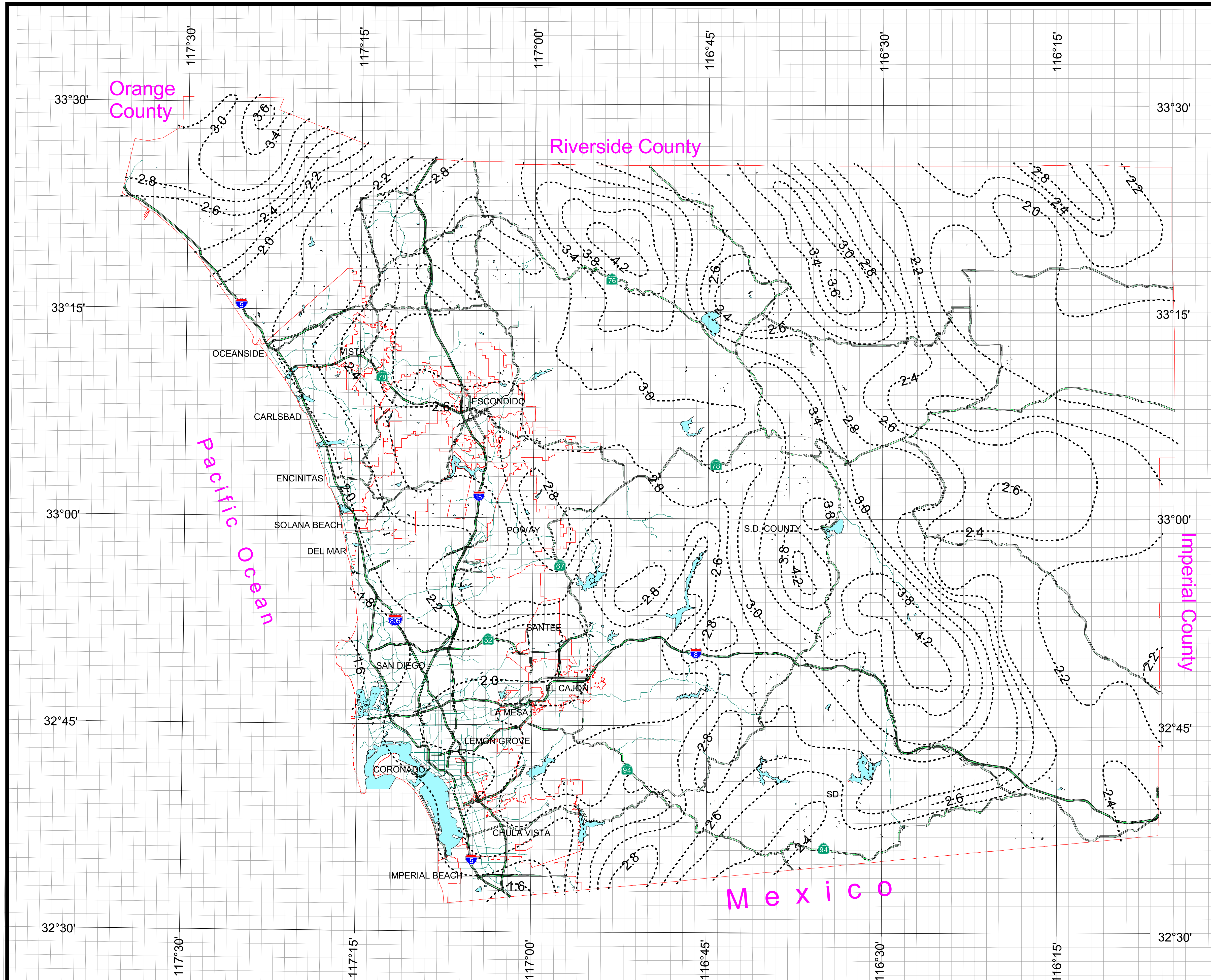
3 0 3 Miles

County of San Diego Hydrology Manual

Rainfall Isopluvials

25 Year Rainfall Event - 6 Hours

Isopluvial (inches)



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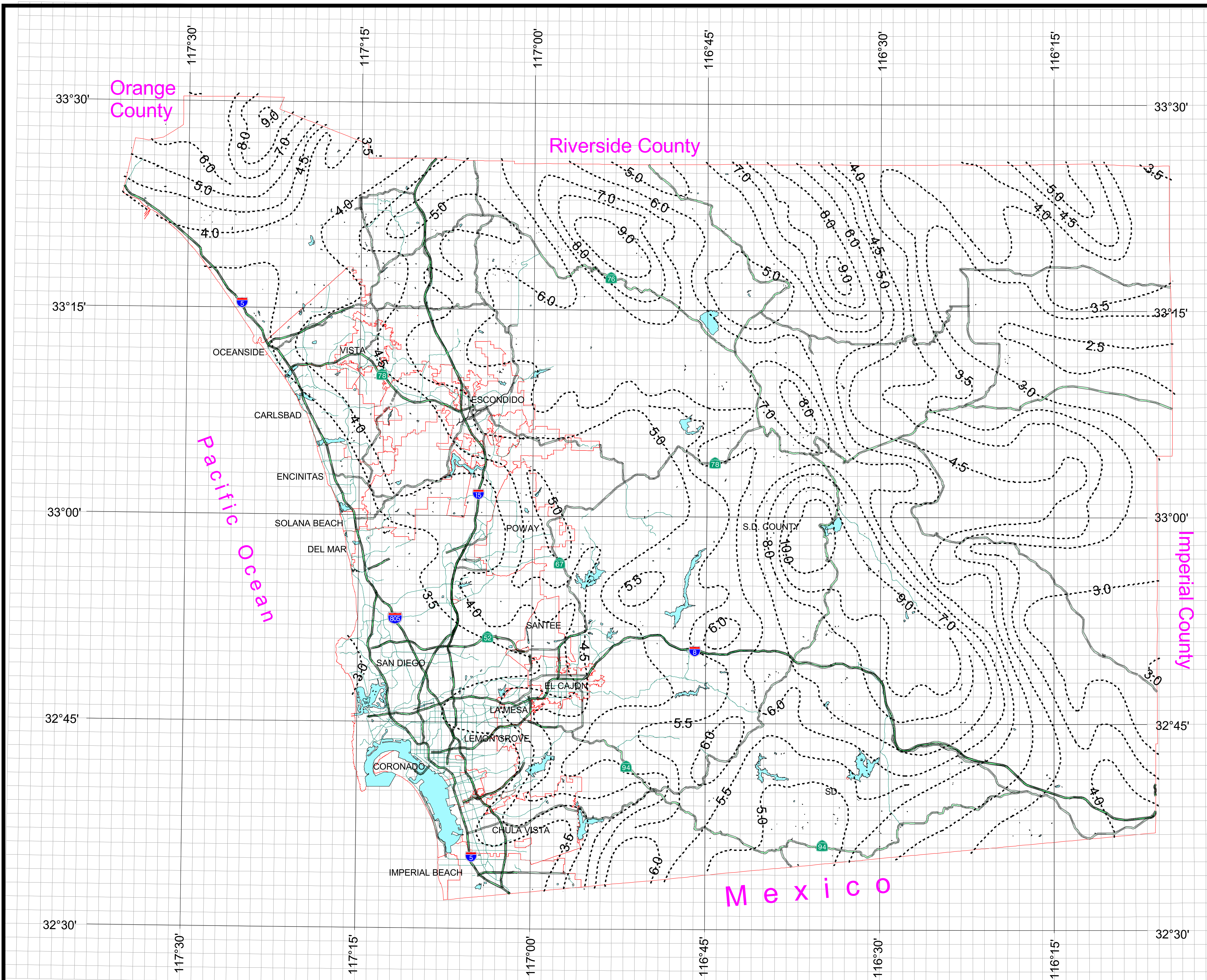
Rainfall Isopluvials

25 Year Rainfall Event - 24 Hours

Isopluvial (inches)



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3 0 3 Miles

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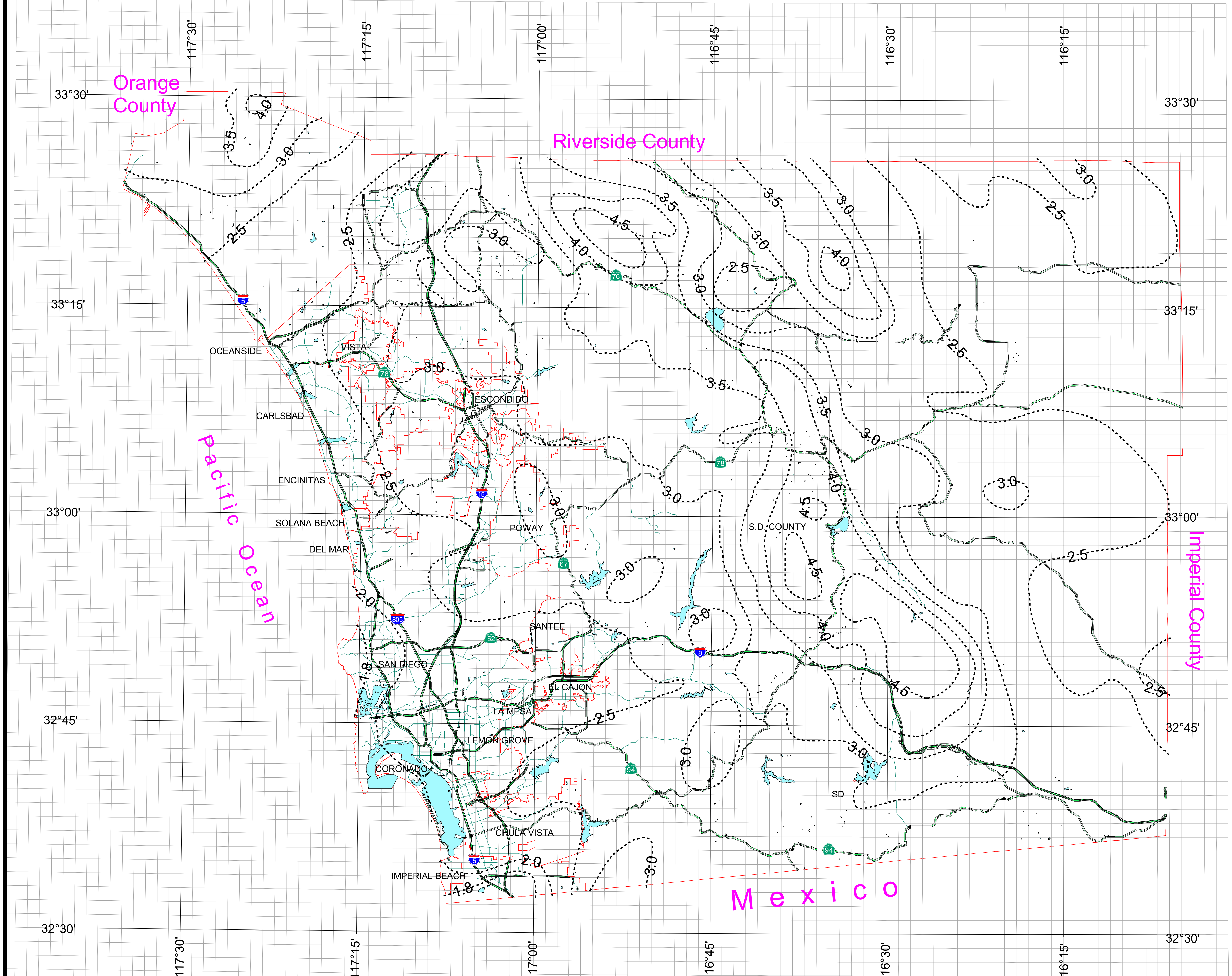
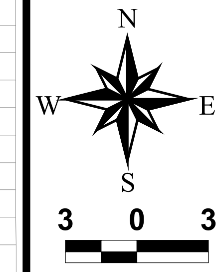
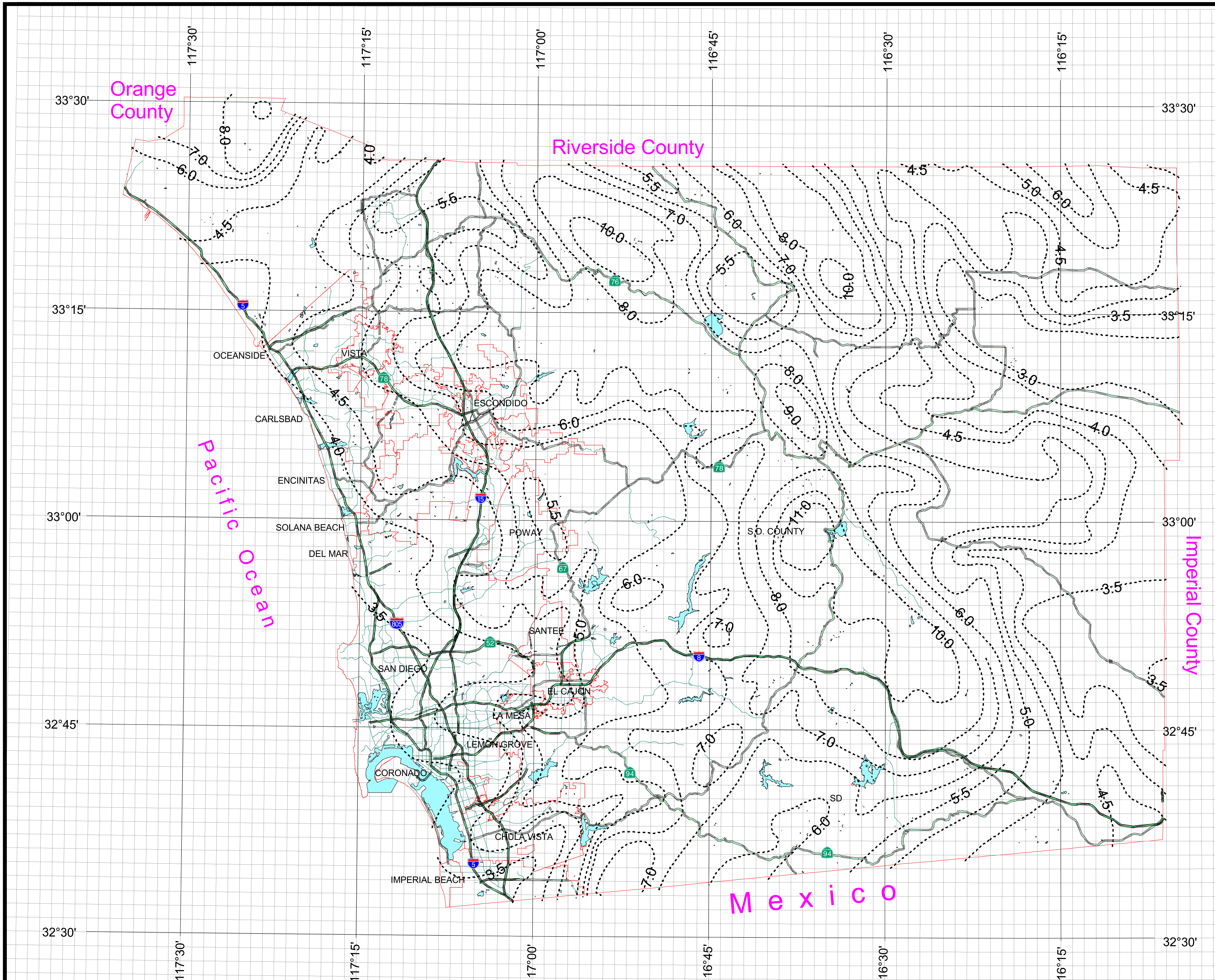
Rainfall Isopluvials



50 Year Rainfall Event - 6 Hours

Isopluvial (inches)





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Rainfall Isopluvials

50 Year Rainfall Event - 24 Hours

Isopluvial (inches)

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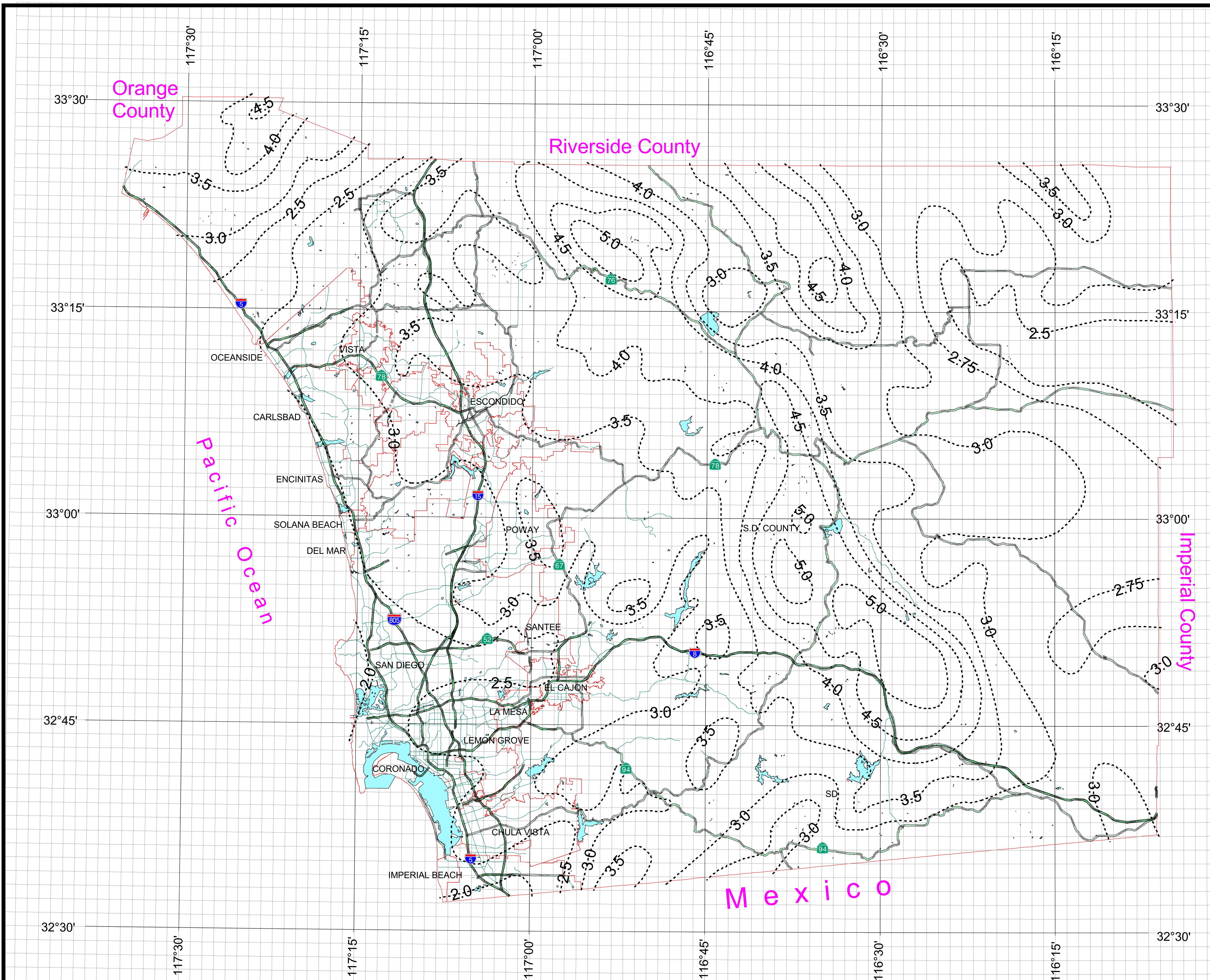
W E
S

3 0 3 Miles



County of San Diego Hydrology Manual

Rainfall Isopluviials

100 Year Rainfall Event - 6 Hours

Isopluvial (inches)

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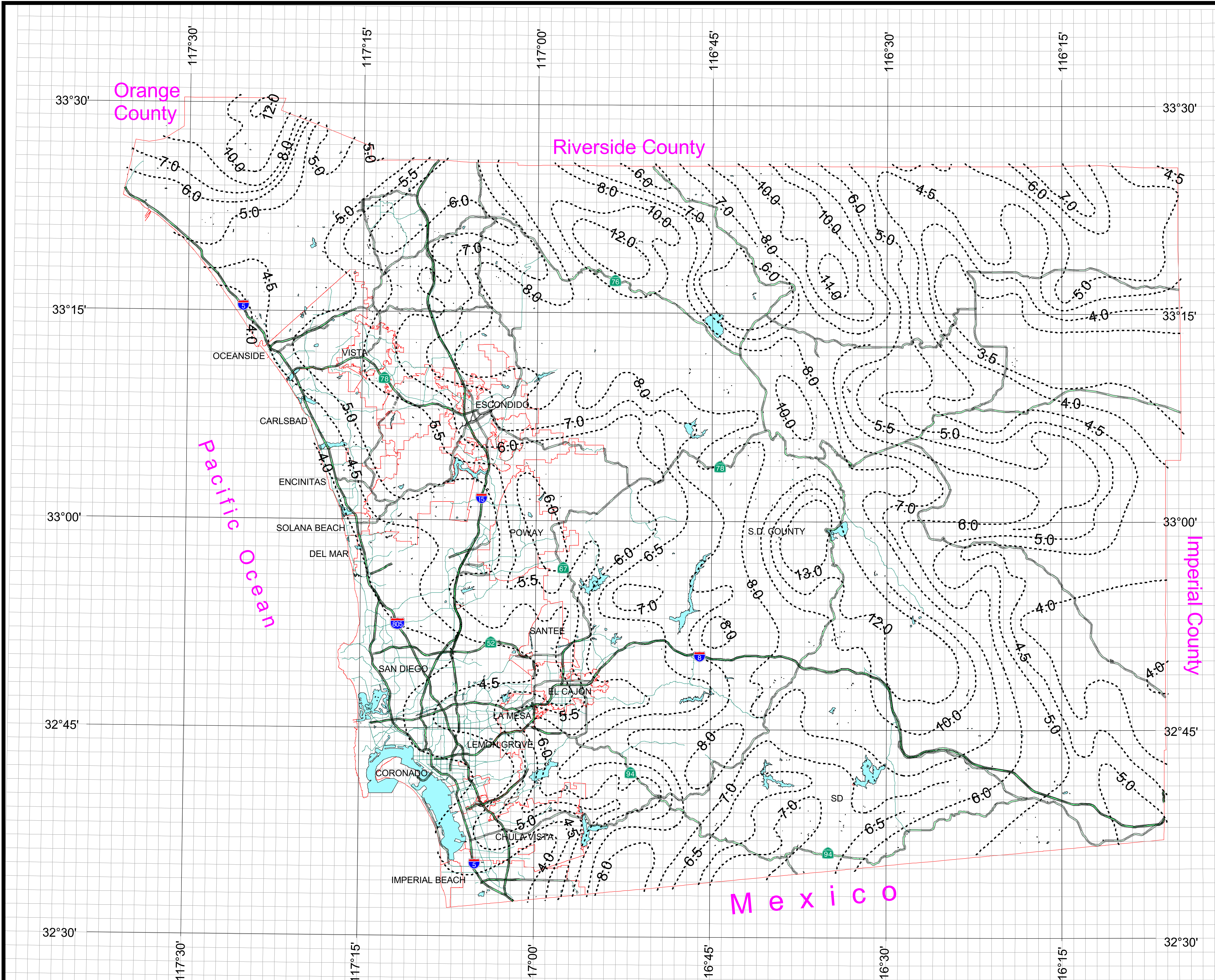
Rainfall Isopluvials

100 Year Rainfall Event - 24 Hours



Isopluvial (inches)

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N
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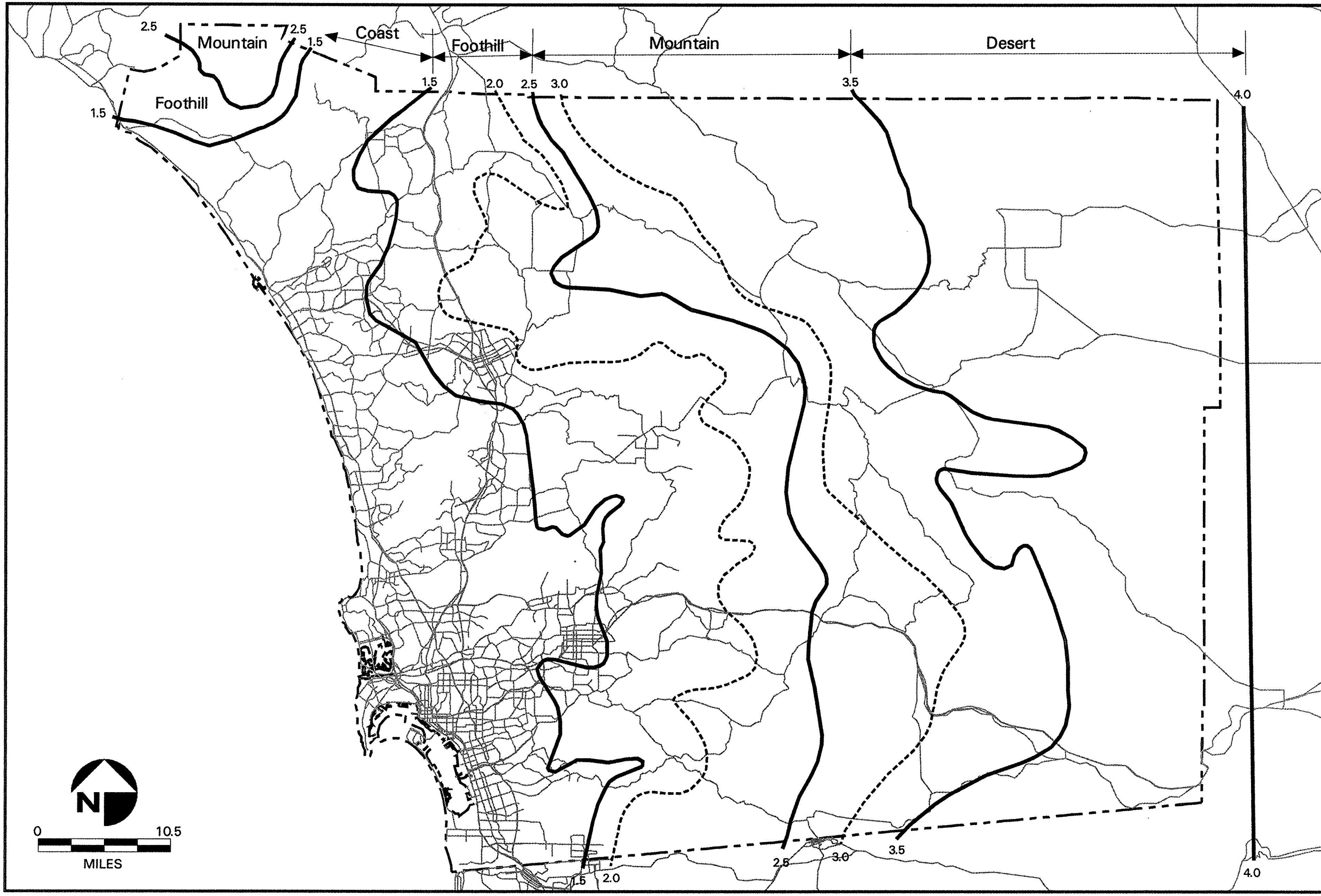
3 0 3 Miles

APPENDIX C

PRECIPITATION ZONE NUMBER (PZN) MAP



FIGURE

C-1

County of San Diego Hydrology Manual

Precipitation Zone Numbers (PZN)

APPENDIX D

WORKSHEETS FOR NRCS HYDROLOGIC METHOD CALCULATIONS

WORKSHEET 4-1 ______________________ **Land Use Worksheet**
(name of project)

DATE BY		HYDROLOGIC CONDITION											
		GOOD 3				FAIR 2				POOR 1			
		A	B	C	D	A	B	C	D	A	B	C	D
FALLOW STRAIGHT ROW	CR												
ROW CROPS STRAIGHT ROW	CR						N/A						
ROW CROPS CONTOURED	CR						N/A						
SMALL GRAIN STRAIGHT ROW	CR						N/A						
SMALL GRAIN CONTOURED	CR						N/A						
CLOSE SEEDED STRAIGHT	CR						N/A						
CLOSE SEEDED CONTOURED	CR						N/A						
IRRIGATED PASTURE	IP												
WATER SURFACES (DURING FLOODS)	WA						N/A				N/A		
ORCHARDS EVERGREEN	OE												
ORCHARDS DECIDUOUS*	OD												
VINEYARDS	VY												
URBAN LOW DENSITY	DL		N/A								N/A		
URBAN MEDIUM DENSITY	DL		N/A								N/A		
URBAN HIGH DENSITY	DL		N/A								N/A		
COMMERCIAL INDUSTRIAL	DL		N/A								N/A		
ANNUAL GRASS	AG												
BROADLEAF CHAPARRAL	BC												
MEADOW	ME												
NARROWLEAF CHAPARRAL	NC		N/A										
OPEN BRUSH	OB												
PERENNIAL GRASS	PG												
WOODLAND GRASS	WG												
WOODS (WOODLAND)	WO												
BARREN	BA		N/A								N/A		
TURF	TU												
FARMSTEADS	FS		N/A								N/A		
ROADS (DIRT)	RD		N/A								N/A		
ROADS (HARD SURFACE)	RD		N/A								N/A		

*For deciduous orchards, select the CN that applies to the land use or the kind and condition of cover during storm periods (winter time). For example, select annual grass CN values for annual grass or grass legume cover. If orchards are kept bare by disking or through the use of herbicides, use fallow CNs.

WORKSHEET 4-2 ______________________ **Curve Number Worksheet**

(name of project)

RUNOFF CURVE NUMBER (for PZN Condition = 2.0) CN_2:

column 1	column 2	column 3	column 4	column 5	column 6
GROUND COVER/ LAND USE	HYDROLOGIC CONDITION (field in-spection)	SOIL GROUP	CN_2 From Hydrology Manual, Table 4-2	FRACTION OF AREA A_i/A	PARTIAL CN_2 $CN_2 \times A_i/A$
			Sums =	1.000	

For entire basin CN_2 = __

WORKSHEET 4-3 ____________________ (name of project) **Peak Discharge Computation**

*****For use with NRCS Hydrologic Method Computations*****

Items in boxes are required input parameters for the SDUH Peak Discharge Program.

Computed by:____ Date:__________

Project Identification (Drainage Area Name): [ ]

Geographic location of center of drainage area: Long:____________" Lat:____________"

Drainage Area: [ ] – square miles

Storm Frequency (Section 2.3): [ ] – year

6-Hour Storm Duration Precipitation (Appendix B): [ ] – inches

24-Hour Storm Duration Precipitation (Appendix B): [ ] – inches

Precipitation Zone Number (PZN): (Section 4.1.2.4 and Appendix C)	PZN = 1.0	_____	2.0	_____	3.0	_____	4.0
PZN Ajustment Factor for 5-year to 35-year storm frequency (interpolate): (Section 4.1.2.4 and Table 4-6)	1.5	_____	2.5	_____	2.0	_____	1.5
PZN Ajustment Factor for 35-year to 150-year storm frequency (interpolate): (Section 4.1.2.4 and Table 4-6)	2.0	_____	3.0	_____	3.0	_____	2.0

PZN Adjusted Runoff Curve Number (interpolate between nearest whole number PZN conditions): $CN_{1.0 \text{ or } 2.0}$ ___ CN_X [ ] $CN_{2.0 \text{ or } 3.0}$ ___
(Sections 4.1.2.4 and 4.2.4, Tables 4-6 and 4-10)

Watershed Length (L) (Section 4.3.1): ________ – miles

Length to Centroid (L_c) (Section 4.3.1): ________ – miles

Slope (s) (Section 4.3.1): ________– feet/mile Basin $\bar{n}$ Factor (Section 4.3.5): ________

Corps lag (T_L) = $24\ \bar{n}\ ((L \times L_c)/s^{0.5})^m$ (Section 4.3.1.1)
OR
Corps lag (T_L) = 0.8 T_c (Section 4.3.1.2) Lag Time: [ ] – hours

Time to Peak = 0.862 x Corps lag (Section 4.1.5.5): Time to Peak : _______ – hours

APPENDIX E

85TH PERCENTILE PRECIPITATION ISOPLUVIAL MAP


85th Percentile Precipitation
Isopluvial Map
Rainfall in Inches
DRAFT
6/27/01
ORANGE COUNTY
RIVERSIDE COUNTY
IMPERIAL COUNTY
MEXICO
PACIFIC OCEAN
OCEANSIDE
CARLSBAD
ENCINITAS
SOLANA BEACH
DEL MAR
SAN DIEGO
CORONADO
IMPERIAL BEACH
NATIONAL CITY
CHULA VISTA
LA MESA
LEMON GROVE
EL CAJON
SANTEE
POWAY
ESCONDIDO
SAN MARCOS
VISTA
Cleveland National Forest
MARINE CORPS AIR STATION MIRAMAR
ANZA BORREGO DESERT STATE PARK
Borrego Springs
Ocotillo Wells
Agua Caliente Springs
Julian
Ramona
Alpine
Boulevard
Jacumba
Tecate
Campo
Miles
0 1 2 4 6 8
Map drawn: July 02, 2001
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THE NOBLEST MOTIVE IS THE PUBLIC GOOD
COUNTY OF SAN DIEGO
MDCCCL
For more information about this map contact County of San Diego, Department of Public Works, SanGIS at (858)495-5775.

WORKBOOK
INTRODUCTION

WB.1 PURPOSE

The purpose of this workbook is to provide example calculations demonstrating the concepts presented in Sections 3, 4, 5, and 6 of the Hydrology Manual. Section 3 of the Hydrology Manual presents the Rational Method (RM) and Modified Rational Method (MRM). Section 4 of the Hydrology Manual presents the Natural Resources Conservation Service (NRCS) unit hydrograph method. Section 5 of the Hydrology Manual presents concepts and procedures for evaluating the erosion potential of a site and sizing desiltation structures, or applying other erosion protection devices to a project. Section 6 of the Hydrology Manual presents the Rational Method Hydrograph procedure. Each example problem references the corresponding Sections of the Hydrology Manual. Figure numbers, Table numbers, and Section numbers that are not preceded by "WB." indicate Figures, Tables, and Sections from the Hydrology Manual. Figure numbers, Table numbers and Section numbers that are preceded by "WB." indicate Figures, Tables, and Sections within this workbook.

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WB.2 Workbook Examples for Hydrology Manual Section 3.0 Rational Method and Modified Rational Method

WB.2.1 Rational Method
(Reference Hydrology Manual Section 3.3)

The following example details the application of the RM for a single-family residential subdivision to calculate the peak flow entering an inlet in the storm drain system. In this example, the 100-year storm event is used. In this example, the soil type (determined from the soils maps in Appendix A of the Hydrology Manual) is uniform across all subareas and is type D. Figure WB.2-1 shows the drainage map for this example.

<u>Flow across the initial subarea</u>

First, consider the initial subarea, nodes 0101 to 0102 in Figure WB.2-1.

C = 0.52 (read from Table 3-1 of the Hydrology Manual for single-family residential, 4.3 dwelling units per acre [DU/A] or less, type D soil)

$A_{0101\text{-}0102}$ = 0.4 acres

$\Sigma(CA)$ = 0.21

L = 220 feet (estimated total flow length after development with house, driveway, garage, etc.) Use 70 feet maximum per Table 3-2 of the Hydrology Manual.

$$s = \frac{332' - 329.5'}{220'}$$ = 0.011 or 1.1% slope (typical value for graded residential lot)

You can neglect the travel time for the remaining 150’ across the pad since it will be small with respect to T_i

T_i = 8.5 minutes (Figure 3-3 of the Hydrology Manual)

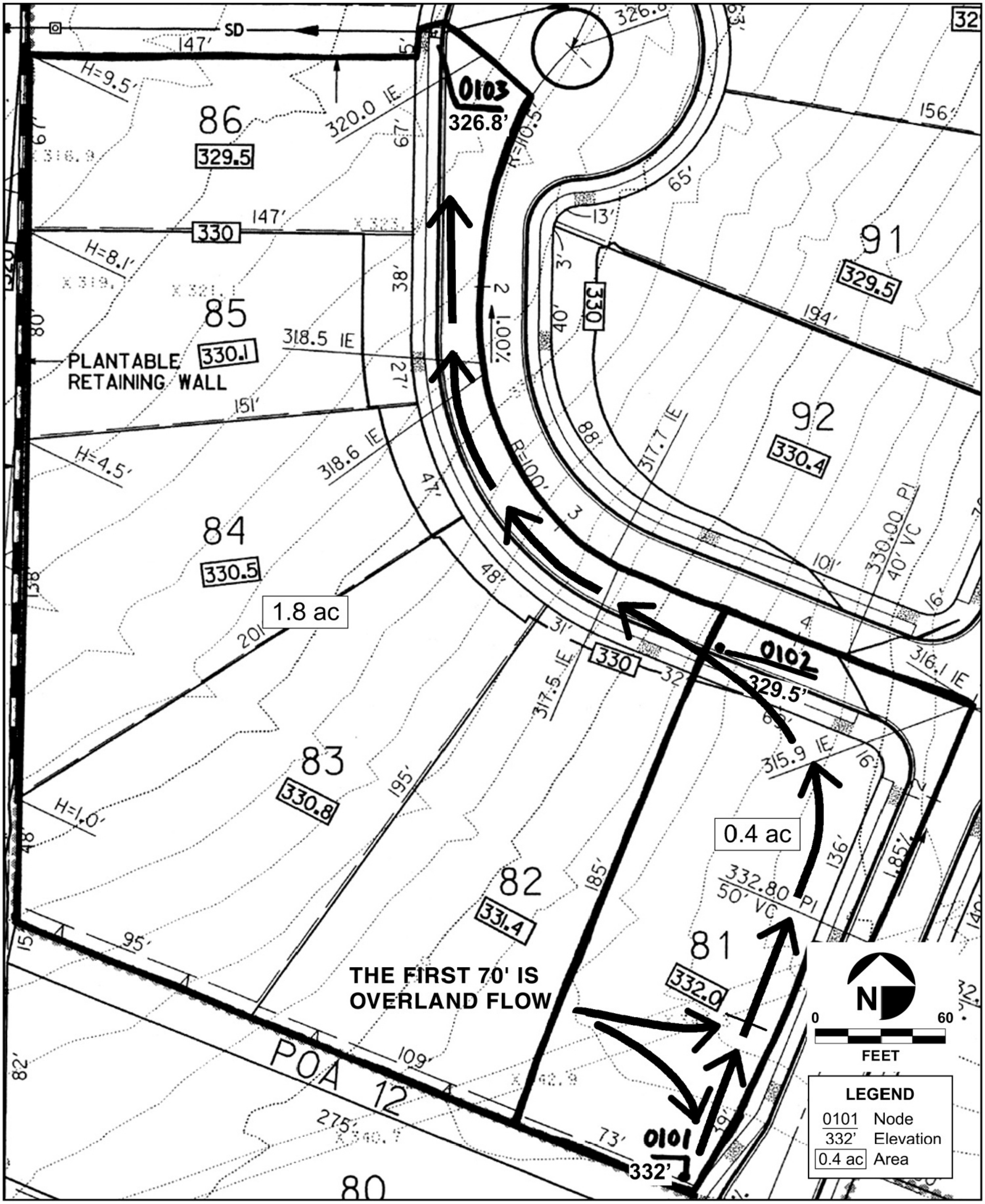


FIGURE WB. 2-1

Example Discharge Area - Rational Method

Using T_i, fill in the worksheet provided in Figure 3-1 of the Hydrology Manual. Use the isopluvial maps (Appendix B of the Hydrology Manual) to read the precipitation over a 6-hour period (P_6) and precipitation over a 24-hour period (P_{24}) for the site. With the adjusted P_6 value determined from the worksheet (Figure 3-1 of the Hydrology Manual), find the intensity, I_{100}. For this example, let P_6 = 2.8 inches, and P_{24} = 4.5 inches. P_6 is within 45% to 65% of P_{24}; therefore, the adjusted P_6 = 2.8 inches.

P_6 = 2.8 inches

I_{100} = 5.2 in/hr

$Q_{0102} = \Sigma(CA)I = 0.21\ (5.2) = 1.1$ cfs

Flow from point 0102 to 0103

The next step is to determine T_t for the length between point 0102 and 0103. The watercourse is a gutter and to calculate T_t it is necessary to know the water velocity, V, in the gutter. However, because the gutter is not a closed conduit, and flow from the subarea is being added, determination of T_t is an iterative process. To find V, assume an average Q over the watercourse (discharges for small watersheds typically range from 2 to 3 cfs per acre, depending on land use, drainage area, slope, and rainfall intensity). This is accomplished using the following method:

- Estimate Q_{AVG} and slope, s_{AVG}, to determine V. Estimate q_{avg} as 2.5 cfs/acre.

  Assume $Q_{AVG} = Q_{0102} + ((q_{avg})(A_{0102\text{-}0103})/2)$

  Q_{AVG} = 1.1 cfs + ((2.5 cfs/acre)(1.8 acres)/2) $\cong$ 3.4 cfs

  $$s_{AVG} = \frac{329.5' - 326.8'}{285'} = 0.01 = 1\%$$

- From Figure 3-6 of the Hydrology Manual, use Q_{AVG} and slope, s_{AVG}, to determine V.

  V = 2.4 fps

Then:

$$T_t = \frac{285'}{2.4 \text{ fps}} = 119 \text{ seconds} = 2.0 \text{ minutes}$$

$$T_c = T_i + T_t = 8.5 + 2.0 = 10.5 \text{ minutes}$$

- Use T_c and the worksheet in Figure 3-1 of the Hydrology Manual to redetermine I'_{100}.

$I'_{100} = 4.6$ in/hr

$Q_p = \Sigma(CA)I$

$$Q_{0103} = [CA_{0101\text{-}0102} + CA_{0102\text{-}0103}]\, I'_{100}$$
$$= [0.52\,(0.4) + 0.52\,(1.8)]\, 4.6 = 5.3 \text{ cfs}$$

Check the earlier assumption that Q_{AVG} from node 0102 to node 0103 was 3.4 cfs.

$Q_{AVG} = Q_{0102} + ((Q_{0103} - Q_{0102})/2)$
$Q_{AVG} = 1.1 + ((5.3 - 1.1)/2) = 3.2 \text{ cfs} \neq 3.4 \text{ cfs}$

At this point, retry the calculation with a different estimate of q_{avg}, say 2.3 cfs/acre for the area from nodes 0102-0103.

Assume $Q_{AVG} = Q_{0102} + (q_{avg})(A_{0102\text{-}0103})$

$Q_{AVG} = 1.1 \text{ cfs} + ((2.3 \text{ cfs/acre})(1.8 \text{ acres})/2) = 3.2 \text{ cfs}$

- From Figure 3-6 of the Hydrology Manual, input Q_{AVG} and slope, s_{AVG}, to determine V.

$V = 2.4$ fps

Then:

$T_t = 285'/2.4 = 119$ seconds $= 2.0$ minutes

$T_c = T_i + T_t = 8.5 + 2.0 = 10.5$ minutes

- Use T_c and the worksheet in Figure 3-1 of the Hydrology Manual to redetermine I'_{100}.

  $I'_{100} = 4.6$ in/hr

  $$Q_{0103} = [CA_{0101\text{-}0102} + CA_{0102\text{-}0103}]\, I'_{100}$$
  $$= [0.52\,(0.4) + 0.52\,(1.8)]\, 4.6 = 5.3 \text{ cfs}$$

  Check the earlier assumption that Q_{AVG} from point 0102 to point 0103 was 3.2 cfs.

  $Q_{AVG} = Q_{0102} + ((Q_{0103} - Q_{0102})/2)$
  $Q_{AVG} = 1.1 + ((5.3 - 1.1)/2) = 3.2$ cfs $= 3.2$ cfs; OK

Final results for node 0103:
$Q_{0103} = 5.3$ cfs
$T_c = 10.5$ minutes
$I_{100} = 4.6$ inches/hour
$A = 0.4 + 1.8 = 2.2$ acres

WB.2.2 MODIFIED RATIONAL METHOD (FOR JUNCTION ANALYSIS) (Reference Hydrology Manual Section 3.4)

WB.2.2.1 Example #1, Junction Equation

The objective of this example is to show how the Q_p and T_c are obtained for a multiple subarea junction. The example is a junction of three independent drainage systems, each with Q_p, T_c, and I calculated by the RM.

(102) Input 1

Q_{p102} = 6.6 cfs
T_{c102} = 10.2 minutes
I_{102} = 4.9 in/hr
A = 2.3 acres

(201) Input 2

Q_{p201} = 10.5 cfs
T_{c201} = 11.2 minutes
I_{201} = 3.1 in/hr
A = 6.1 acres

(301) Input 3

Q_{p301} = 17.6 cfs
T_{c301} = 9.8 minutes
I_{301} = 5.1 in/hr
A = 4.7 acres

When the three inputs are inserted into the junction equation, the result is:

$$T_1 < T_2 < T_3$$

$$T_{301} < T_{102} < T_{201}$$

$$Q_{T1} = Q_{301} + \frac{T_{301}}{T_{102}} Q_{102} + \frac{T_{301}}{T_{201}} Q_{201}$$

$$= 17.6 + \frac{9.8}{10.2} (6.6) + \frac{9.8}{11.2} (10.5)$$

$$= 33.1$$

$$Q_{T2} = Q_{102} + \frac{I_{102}}{I_{301}} Q_{301} + \frac{T_{102}}{T_{201}} Q_{201}$$

$$= 6.6 + \frac{4.9}{5.1} (17.6) + \frac{10.2}{11.2} (10.5)$$

$$= 33.1$$

$$Q_{T3} = Q_{201} + \frac{I_{201}}{I_{301}} Q_{301} + \frac{I_{201}}{I_{102}} Q_{102}$$

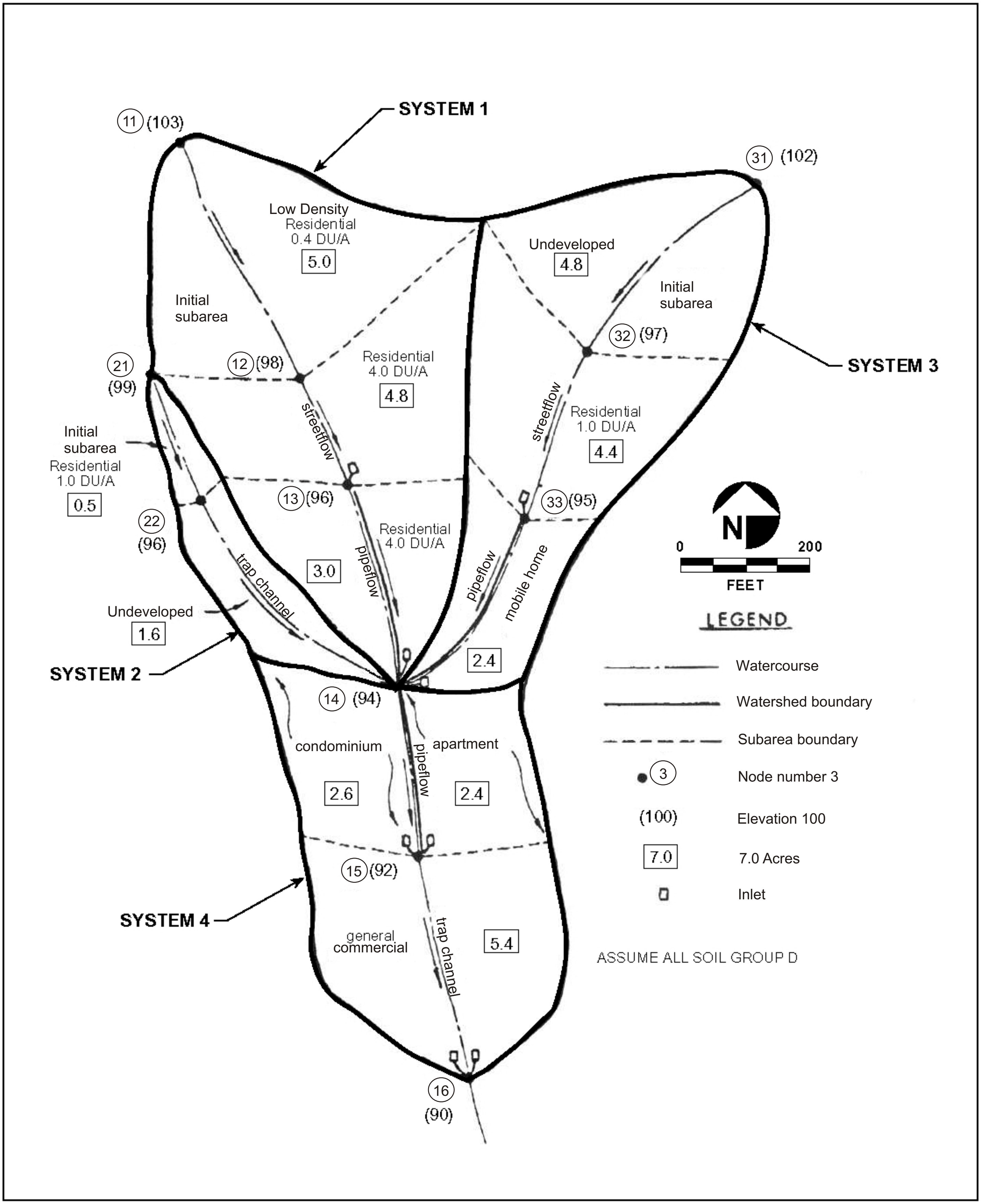
$$= 10.5 + \frac{3.1}{5.1} (17.6) + \frac{3.1}{4.9} (6.6)$$

$$= 25.4$$

Select the largest Q and use the T_c associated with that Q for further calculations. In this case, $Q_{T1} = Q_{T2} > Q_{T3}$. Select the shorter of the T_c's associated with the larger Q. Use: $Q_{T1} = 33.1$ cfs and $T_1 = 9.8$ minutes for downstream calculations.

WB.2.2.2 Example #2, Modified Rational Method

This example demonstrates application of the MRM for a small urban watershed. Figure WB.2-2 shows a schematic of the watershed. The northern portion of the watershed is composed of three independent drainage systems that drain to a junction at node 14. A single drainage system continues from node 14 to node 16. Subareas have been defined based on land use, topography, and drainage structures, and node numbers have been placed at points of interest. Data for the example problem are given in Table WB.2-1. The procedure for calculating flow for each subarea is described in the text below. Table WB.2-2 presents a summary of the results. For this example, assume P_6 = 2.5 inches and P_{24} = 5.7 inches.



Example Discharge Area -
Modified Rational Method Example #2

FIGURE

WB.2-2

Table WB.2-1

INPUT DATA FOR MODIFIED RATIONAL METHOD EXAMPLE #2

Upstream Node	Downstream Node	Area (acres)	Runoff Coefficient*	Upstream Elevation (ft)	Downstream Elevation (ft)	Length (ft)	Drainage System
System 1							
11	12	5.0	0.41	103	98	400	Initial Subarea
12	13	4.8	0.52	98	96	175	Street Flow
13	14	3.0	0.52	96	94	325	Pipe Flow
System 2							
21	22	0.5	0.41	99	96	200	Initial Subarea
22	14	1.6	0.35	96	94	425	Trapezoidal Channel
System 3							
31	32	4.8	0.35	102	97	375	Initial Subarea
32	33	4.4	0.41	97	95	275	Street Flow
33	14	2.4	0.79	95	94	350	Pipe Flow
System 4							
14	15	2.6 and 2.4	0.63 and 0.71	94	92	275	Pipe Flow
15	16	5.4	0.82	92	90	350	Trapezoidal Channel

* For the purpose of this example, some assumptions were made about land use categories for selection of the runoff coefficient (e.g., the number of dwelling units per acre was assumed for condominiums, apartments, and mobile homes; and "undeveloped" land was assumed to be permanently undeveloped). The engineer must consult the Tentative Map(s) for the area(s) or the community's General Plan for this information.

Table WB.2-2

SUMMARY OF MODIFIED RATIONAL METHOD EXAMPLE #2 CALCULATIONS

Upstream Node	Downstream Node	Area (acres)	Runoff Coefficient	ΣA (acres)	Σ(CA) (acres)	ΣTc (minutes)	I (inches/hour)	Q (cfs)
System 1								
11	12	5.0	0.41	5.0	2.1	13.2	3.7	7.8
12	13	4.8	0.52	9.8	4.6	14.1	3.5	16.1
13	14	3.0	0.52	12.8	6.2	15.1	3.4	21.0
System 2								
21	22	0.5	0.41	0.5	0.2	9.1	4.7	0.9
22	14	1.6	0.35	2.1	0.8	13.8	3.6	2.9
System 3								
31	32	4.8	0.35	4.8	1.7	13.7	3.6	6.1
32	33	4.4	0.41	9.2	3.5	15.5	3.3	11.6
33	14	2.4	0.79	11.6	5.4	16.4	3.2	17.3
Junction of Systems 1 through 3				26.5				39.7
System 4								
14	15	2.6 and 2.4	0.63 and 0.71	31.5	15.7	15.6	3.3	51.8
15	16	5.4	0.82	36.9	20.1	16.5	3.2	64.3

The first step is to calculate T_c, intensity, peak flow, and area for each of the three independent drainage systems draining to node 14.

System 1:

Flow at node 14 from System 1 (Q_1) is composed of flow in a pipe from two upstream subareas draining to node 13, and additional subarea flow from the area between nodes 13-14. The initial subarea is a low density residential development in which impervious areas are not directly connected to a storm drain system.

1. Overland flow across low density residential initial subarea nodes 11-12

$C_{11-12} = 0.41$
$A_{11-12} = 5.0$ acres
$\Sigma(CA) = (0.41)(5.0) = 2.1$

L = 400 feet (use 70 feet maximum length per Table 3-2 of the Hydrology Manual to determine T_i).
$\Delta E = 103 - 98 = 5$ feet
$S = (103\text{-}98)/400 = 1.3\%$

To determine the time of concentration, first use a 70' maximum length per Table 3-2 of the Hydrology Manual to determine T_i using the overland time of flow nomograph (Figure 3-3 of the Hydrology Manual). Because the initial subarea is a low density development in which impervious areas are not directly connected to a storm drain system, use the Kirpich formula (Figure 3-4 of the Hydrology Manual) to determine the travel time T_t across the remaining 330' of length in the subarea.

From Figure 3-3 of the Hydrology Manual, T_i = 9.5 minutes for the initial 70' travel length

From Figure 3-4 of the Hydrology Manual, T_t.= 3.7 minutes

The total time of concentration across rural initial subarea nodes 11-12 is 9.5 + 3.7 =13.2 minutes

Use Figure 3-1 of the Hydrology Manual to determine I. First, check that P_6 is within 45% - 65% of P_{24}.

$P_6 = 2.5$ inches
$P_{24} = 5.7$ inches
$P_6/P_{24} = 2.5 / 5.7 = 0.44$ (44%)
Since P_6 is less than 45% of P_{24}, increase P_6 to 2.6 inches
$P_6/P_{24} = 2.6 / 5.7 = 0.46$ (46%)
Use $P_6 = 2.6$ inches for all intensity calculations

From Figure 3-1 of the Hydrology Manual, I = 3.7 inches/hour

$Q_{12} = \Sigma(CA)I = (2.1)(3.7) = 7.8$ cfs

2. Street flow from nodes 12-13

Because the gutter is not a closed conduit, additional flow from the subarea is being added during the T_t time of flow from nodes 12-13. An average flow must be assumed for the gutter to determine velocity in the gutter, T_c, and total flow at node 13.

$C_{12\text{-}13} = 0.52$
$A_{12\text{-}13} = 4.8$ acres
$\Sigma(CA) = [2.1 + ((0.52)(4.8))] = 4.6$

$L = 175$ feet
$S = (98 – 96) / 175 = 0.011$ (1.1%)

Assume Q_{AVG} from nodes 12-13 $= Q_{12} + (q_{avg})(A_{12\text{-}13}/2)$.
Assume q_{avg} is 2.0 cfs/acre.

$Q_{AVG} = 7.8 + (2)(4.8/2) = 12.6$ cfs

From Figure 3-6 of the Hydrology Manual, $V = 3.3$ fps

$T_t = (L/V)(1/60) = (175/3.3)(1/60) = 0.9$ minutes

$T_{c13} = T_i + T_t = 13.2 + 0.9 = 14.1$ minutes

From Figure 3-1 of the Hydrology Manual, $I = 3.5$ inches/hour

$Q_{13} = \Sigma(CA)I = (4.6)(3.5) = 16.1$ cfs

Check the assumption that $Q_{AVG} = 12.6$ cfs:

$Q_{AVG} = Q_{12} + ((Q_{13}\text{-}Q_{12})/2) = 7.8 + ((16.1 – 7.8)/2) = 12.0 \text{ cfs} \neq 12.6$ cfs

Try again assuming q_{avg} is 1.8 cfs/acre.
Again assume Q_{AVG} from nodes 12-13 $= Q_{12} + (1.8 \text{ cfs/acre})(A_{12\text{-}13}/2)$.

$Q_{AVG} = 7.8 + (1.8)(4.8/2) = 12.1$ cfs

From Figure 3-6 of the Hydrology Manual, $V = 3.2$ fps

$T_t = (L/V)(1/60) = (175/3.2)(1/60) = 0.9$ minutes

$T_{c13} = T_i + T_t = 13.2 + 0.9 = 14.1$ minutes

From Figure 3-1 of the Hydrology Manual, $I = 3.5$ inches/hour

$Q_{13} = \Sigma(CA)I = (4.6)(3.5) = 16.1$ cfs

Check the assumption that $Q_{AVG} = 12.1$ cfs:

$Q_{AVG} = Q_{12} + ((Q_{13}\text{-}Q_{12})/2) = 7.8 + ((16.1 - 7.8)/2) = 12.0 \text{ cfs} \cong 12.1 \text{ cfs, OK}$

3. Pipe flow from nodes 13-14 and addition of subarea flow:

Because the pipe is a closed conduit, no additional subarea flow is added to the pipe during travel, and the T_t for flow in the pipe is based on the flow in the pipe. The subarea flow from the area between nodes 13-14 is added into the pipe at node 14 by adding the additional CA for the area between nodes 13-14 to the previous total CA from node 13 and multiplying the total by the intensity at node 14. This will give the new peak discharge in the pipe at node 14. If an inlet is to be designed for the subarea flow between nodes 13-14, then a peak discharge for basin 13-14 should be calculated and a junction analysis should be done at node 14 to combine these flows.

$Q_{13} = 16.1$ cfs in the pipe (from node 13)

A 30-inch pipe can adequately convey 16.1 cfs at a slope of 0.6%. Assume a 30-inch pipe will be used; $V = 6.5$ fps

$T_t = 375/6.5(1/60) = 1.0$ minutes

$T_{c14} = T_{c13} + T_{t13\text{-}14} = 14.1 + 1.0 = 15.1$ minutes

From Figure 3-1 of the Hydrology Manual, $I = 3.4$ inches/hour

$C_{13\text{-}14} = 0.52$
$A_{13\text{-}14} = 3.0$
$\Sigma(CA) = [4.6 + (0.52)(3.0)] = 6.2$

System 1 Summary:

$Q_1 = \Sigma(CA)I = 6.2(3.4) = 21.0$ cfs

$T_{c1} = 15.1$ minutes

$I_1 = 3.4$ inches/hour

$A_1 = 5 + 4.8 + 3.0 = 12.8$ acres

System 2:

Flow at node 14 from System 2 (Q_2) is composed of flow in the trapezoidal channel from the subarea draining to node 22, and additional subarea flow from the area between nodes 22-14.

1. Overland flow across urban initial subarea nodes 21-22:

$C_{21\text{-}22} = 0.41$

$A_{21\text{-}22} = 0.5$ acres

$\Sigma(CA) = (0.41)(0.5) = 0.2$

L = 200 feet (use 70 feet maximum per Table 3-2 of the Hydrology Manual)

You can neglect the travel time for the remaining 130' across the pad since it will be small with respect to the T_i

$S = (99 - 96)/200 = 0.015$ (1.5%)

From Figure 3-5 of the Hydrology Manual, $T_i = 9.1$ minutes

From Figure 3-1 of the Hydrology Manual, $I = 4.7$ inches/hour

$Q_{32} = \Sigma(CA)I = (0.2)(4.7) = 0.9$ cfs

2. Channel flow from nodes 22-14 and addition of subarea flow:

For this example, the channel from nodes 22-14 is assumed to be a natural channel. Because the channel is not a closed conduit, additional flow from the subarea is being added during the T_t of flow from nodes 22-14. An average flow must be assumed for the channel to determine velocity in the channel, T_c, and total flow from System 2 at node 14.

$C_{22\text{-}14} = 0.35$
$A_{22\text{-}14} = 1.6$ acres
$\Sigma(CA) = [0.2 + ((0.35)(1.6))] = 0.8$

$L = 425$ feet
$S = (96 - 94) / 425 = 0.005$ (0.5%)

Assume q_{avg} is 1.1 cfs/acre.
Assume Q_{AVG} from nodes 22-14 $= Q_{22} + (1 \text{ cfs/acre})(A_{22\text{-}14}/2)$.

$Q_{AVG} = 0.9 + (1.1)(1.6/2) = 1.8$ cfs

Assume that the channel is vegetated, and $n = 0.035$.
A 1-foot-wide channel with 1.5:1 side slopes can adequately convey the flow in the channel. Assume $V \cong 1.5$ fps.

$T_t = (L/V)(1/60) = (425/1.5)(1/60) = 4.7$ minutes

$T_c = T_i + T_t = 9.1 + 4.7 = 13.8$ minutes

From Figure 3-1 of the Hydrology Manual, $I = 3.6$ inches/hour

$Q_{14} = \Sigma(CA)I = (0.8)(3.6) = 2.9$ cfs

Check the assumption that $Q_{AVG} = 1.8$ cfs:

$Q_{AVG} = Q_{22} + ((Q_{22}\text{-}Q_{14})/2) = 0.9 + ((2.9 - 0.9)/2) = 1.9 \text{ cfs} \cong 1.8$ cfs; OK

System 2 Summary:

Q_2 = 2.9 cfs

T_{c2} = 13.8 minutes

I_2 = 3.6 inches/hour

A_2 = 0.5 + 1.6 = 2.1 acres

System 3:

Flow at node 14 from System 3 (Q_3) is composed of flow in the pipe from the subareas draining to node 33, and additional subarea flow from the area between nodes 33-14.

1. Overland flow across natural initial subarea nodes 31-32:

C_{31-32} = 0.35

A_{31-32} = 4.8 acres

$\Sigma(CA)$ = (0.35)(4.8) = 1.7

ΔE = 102 – 97 = 5 feet

L = 375 feet

S = (102-97)/375 = 0.013 = 1.3%

From Figure 3-5 of the Hydrology Manual, T_i = 10.3 minutes

To determine the time of concentration, first use a 70' maximum length per Table 3-2 of the Hydrology Manual to determine T_i, then use the Kirpich formula (Figure 3-4 of the Hydrology Manual) to determine the travel time T_t across the remaining 305' of length in the subarea. The total time of concentration across natural initial subarea nodes 31-32 is 10.3 + 3.4 = 13.7 minutes.

From Figure 3-1 of the Hydrology Manual, I = 3.6 inches/hour

$Q_{32} = \Sigma(CA)I$ = (1.7)(3.6) = 6.1 cfs

2. Street flow from nodes 32-33

Because the gutter is not a closed conduit, additional flow from the subarea is being added during the T_t of flow from nodes 32-33. An average flow must be assumed for the gutter to determine velocity in the gutter, T_c, and total flow at node 33.

$C_{32\text{-}33} = 0.41$
$A_{32\text{-}33} = 4.4$ acres
$\Sigma(CA) = [1.7 + ((0.41)(4.4))] = 3.5$

$L = 275$ feet
$S = (97 - 95) / 275 = 0.007$ (0.7%)

Assume q_{avg} is 1.2 cfs/acre.
Assume Q_{AVG} from nodes 32-33 $= Q_{32} + (1.2 \text{ cfs/acre})(A_{32\text{-}33}/2)$.

$Q_{AVG} = 6.1 + (1.2)(4.4/2) = 8.7$ cfs

From Figure 3-6 of the Hydrology Manual, $V = 2.6$ fps

$T_t = (L/V)(1/60) = (275/2.6)(1/60) = 1.8$ minutes

$T_{c33} = T_i + T_t = 13.7 + 1.8 = 15.5$ minutes

From Figure 3-1 of the Hydrology Manual, $I = 3.3$ inches/hour

$Q_{33} = \Sigma(CA)I = (3.5)(3.3) = 11.6$ cfs

Check the assumption that $Q_{AVG} = 8.7$ cfs:

$Q_{AVG} = Q_{32} + ((Q_{33}\text{-}Q_{32})/2) = 6.1 + ((11.6 - 6.1)/2) = 8.9 \text{ cfs} \cong 8.7$ cfs; OK

3. Pipe flow from nodes 33-14 and addition of subarea flow:

Because the pipe is a closed conduit, no additional subarea flow is added to the pipe during travel, and the T_t for flow in the pipe is based on the flow in the pipe. As above for System 1, since we are not sizing an inlet for the subarea from nodes 33-14, the subarea flow from the area between nodes 33-14 is added into the pipe at node 14 by adding the additional CA for the area between nodes 33-14 to the previous total CA from node 33 and multiplying the total by the intensity at node 14. This will give the new peak discharge in the pipe at node 14.

Q_{33} = 11.6 cfs in the pipe (from node 33)

A 24-inch pipe can adequately convey 11.6 cfs at a slope of 0.7%. Assume a 24-inch pipe will be used; V = 6.3 fps

$T_t = (350/6.3)(1/60) = 0.9$ minutes

$T_{c14} = T_{c33} + T_{t33\text{-}14} = 15.5 + 0.9 = 16.4$ minutes

From Figure 3-1 of the Hydrology Manual, I = 3.2 inches/hour

$C_{33\text{-}14} = 0.79$

$C_{33\text{-}14}$ = 2.4 acres

$\Sigma(CA) = [3.5 + ((0.79)(2.4))] = 5.4$

$\Sigma(CA)I = (5.4)(3.2) = 17.3$ cfs

System 3 Summary:

Q_3 = 17.3 cfs

T_{c3} = 16.4 minutes

I_3 = 3.2 inches/hour

$A_3 = 4.8 + 4.4 + 2.4 = 11.6$ acres

Junction of Systems 1 through 3

The second step is to combine the three independent drainage systems draining to node 14. To combine independent drainage systems 1 through 3, a junction analysis will be used. Table WB.2-3 summarizes the junction data for the three systems.

Table WB.2-3

**SUMMARY OF CONFLUENCE DATA FOR
MODIFIED RATIONAL METHOD EXAMPLE #2
SYSTEMS 1 THROUGH 3**

System	Q (cfs)	T_c (minutes)	I (inches/hour)	A (acres)	ΣCA
1 = Y	21.0	15.1	3.4	12.8	6.2
2 = X	2.9	13.8	3.6	2.1	0.8
3 = Z	17.3	16.4	3.2	11.6	5.4

When the three inputs are inserted into the junction equation, the result is:

$T_2 < T_1 < T_3$

Since the Systems were identified by number, let $T_2 = T_X$, $T_1 = T_Y$, and $T_3 = T_Z$

$T_X < T_Y < T_Z$

$$Q_{TX} = Q_X + \frac{T_X}{T_Y} Q_Y + \frac{T_X}{T_Z} Q_Z$$

$$= 2.9 + (13.8/15.1)(21.0) + (13.8/16.4)(17.3)$$

$$= 36.6$$

$$Q_{TY} = Q_Y + \frac{I_Y}{I_X} Q_X + \frac{T_Y}{T_Z} Q_Z$$

$$= 21.0 + (3.4/3.6)(2.9) + (15.1/16.4)(17.3)$$

$$= 39.7$$

$$Q_{TZ} = Q_Z + \frac{I_Z}{I_X} Q_X + \frac{I_Z}{I_Y} Q_Y$$

$$= 17.3 + (3.2/3.6)(2.9) + (3.2/3.4)(21.0)$$

$$= 39.6$$

Select the largest Q and use the T_c associated with that Q for further calculations.

Use $Q_{TY} = 39.7$ cfs and $T_Y = 15.1$ minutes.

The total area associated with this system is the sum of the drainage areas for the three contributing systems:

$A = A_1 + A_2 + A_3 = 12.8 + 2.1 + 11.6 = 26.5$ acres
$\Sigma CA = CA_1 + CA_2 + CA_3 = 6.2 + 0.8 + 5.4 = 12.4$

System 4: Continuation of Single System to Node 16

The third step is to continue the analysis of the single system from node 14 using Q, A, and T_c from the junction analysis:

Q_{14} = 39.6 cfs
T_{c14} = 15.1 minutes
A_{14} = 26.5 acres
$\Sigma CA = 12.4$

3. Pipe flow from nodes 14-15 and addition of subarea flow:

Because the pipe is a closed conduit, no additional subarea flow is added to the pipe during travel, and the T_t for flow in the pipe is based on the flow in the pipe. As above for Systems 1 and 3, since we are not sizing inlets for the subareas between nodes 14-15, flow is added into the pipe at node 15 by adding the additional CA for the area between nodes 14-15 to the previous total CA from node 14 and multiplying the total by the intensity at node 15. This will give the new peak discharge in the pipe at node 15.

L = 275 feet
S = (94-92)/275 = 0.007 (0.7%)

A 36-inch pipe can adequately convey 40.5 cfs at a slope of 0.7%. Assume a 36-inch pipe will be used; V = 8.6 fps

T_t = (275/8.6)(1/60) = 0.5 minutes

$T_{c15} = T_{c14} + T_{t14\text{-}15} = 15.1 + 0.5 = 15.6$ minutes

From Figure 3-1 of the Hydrology Manual, I = 3.3 inches/hour

$C_{14\text{-}15}$ = 0.63 and 0.71
$A_{14\text{-}15}$ = 2.6 and 2.4 acres

$\Sigma(CA) = [12.4 + (0.63)(2.6) + (0.71)(2.4)] = 15.7$

$Q_{15} = \Sigma(CA)I = (15.7)\,3.3 = 51.8$ cfs
$T_{c15} = 15.6$ minutes
$I = 3.3$ inches/hour
$A = 26.5 + 2.6 + 2.4 = 31.5$ acres
$\Sigma CA = 15.7$

4. Flow in trapezoidal channel from nodes 15-16 and addition of subarea flow:

For the general commercial area, the trapezoidal channel should be considered as a closed conduit because the subarea flow is directed to inlets. With no additional subarea flow added to the channel during travel, the T_t for flow in the channel is based on the total flow in the channel from node 15. As for the pipes sized above, since we are not sizing inlets for the subarea between nodes 15-16, the subarea flow from the areas between nodes 15-16 will be added directly to the total flow in the pipe at node 16 using the T_c for the flow in the pipe.

$L = 350$ feet
$S = (92-90)/350 = 0.006\ (0.6\%)$

Assume that the channel is concrete, and $n = 0.018$
A 1-foot-wide channel with 1.5:1 side slopes can adequately convey 51.8 cfs at a slope of 0.6%. Assume $V \cong 6.3$ fps.

$T_{t15\text{-}16} = (350/6.3)(1/60) = 0.9$ minutes

$T_{c16} = T_{c15} + T_{t15\text{-}16} = 15.6 + 0.9 = 16.5$ minutes

From Figure 3-1 of the Hydrology Manual, $I = 3.2$ inches/hour

$C_{15\text{-}16}$ = 0.82

$A_{15\text{-}16}$ = 5.4 acres

$\Sigma(CA) = 15.7 + (0.82)(5.4) = 20.1$

$\Sigma(CA)I = (20.1)(3.2) = 64.3$ cfs

<u>System 4 Summary</u>:

Q_{16} = 64.3 cfs

T_{c16} = 16.5 minutes

I = 3.2 inches/hour

A = 31.5 + 5.4 = 36.9 acre

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WB.3 WORKBOOK EXAMPLES FOR HYDROLOGY MANUAL SECTION 4.0 NATURAL RESOURCES CONSERVATION SERVICE HYDROLOGIC METHOD

The first example problem in this Section demonstrates the computation of the CN, Corps lag, and T_p values based on NRCS methods and data, and demonstrates the use of the SDUH Peak Discharge Program to obtain the peak discharge. The second example problem demonstrates the development of the rainfall distribution, calculation of excess rainfall, preparation of unit hydrograph ordinates, and convolution of the runoff hydrograph by hand computation. The results of the hand computation are compared to results from the SDUH Peak Discharge Program and HEC-1.

WB.3.1 NRCS Hydrologic Method Example #1, Computation of CN, Corps Lag, T_p, and Peak Discharge

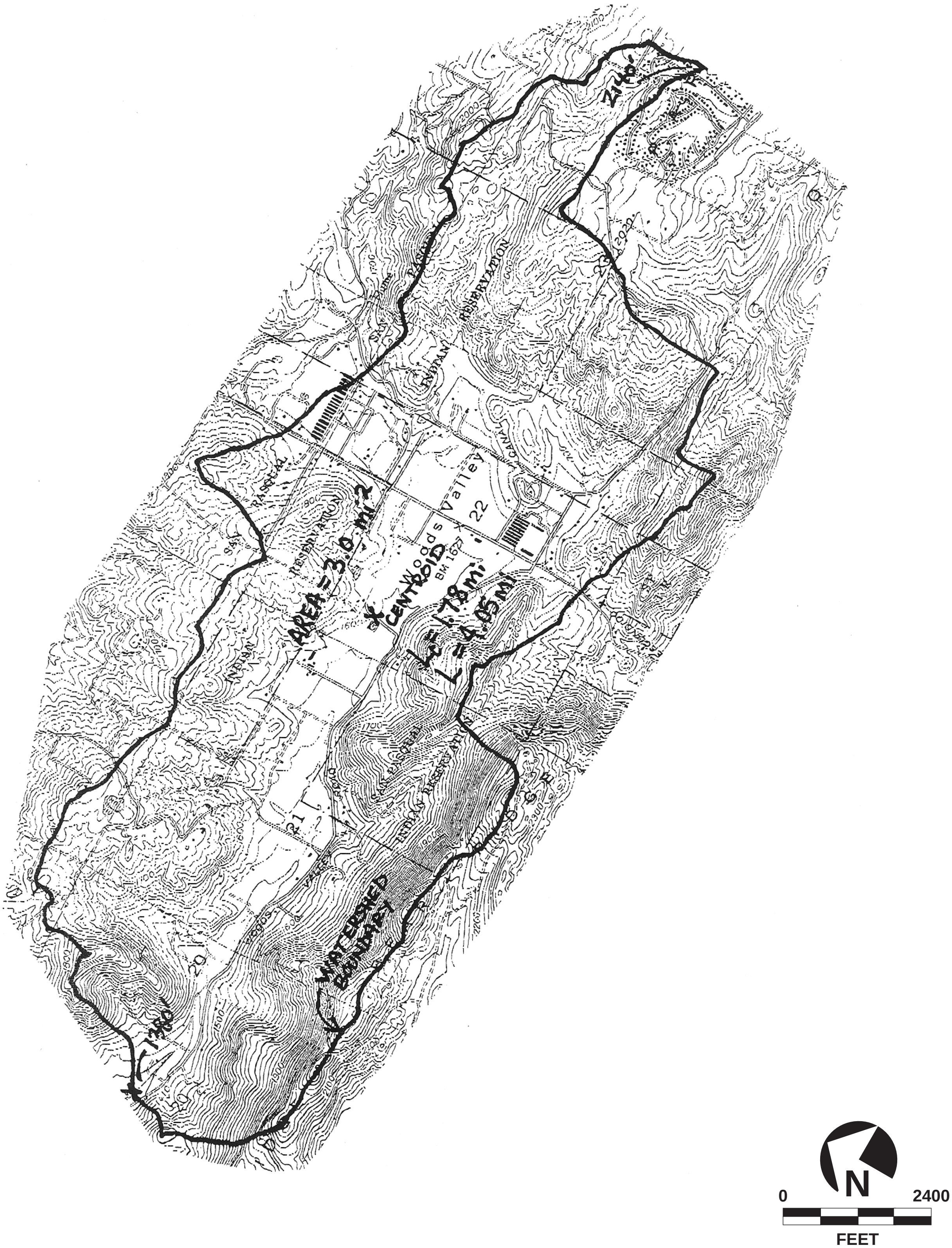
(Reference Hydrology Manual Sections 4.2 and 4.3)

This example is a 100-year storm event for a 3-square-mile watershed.

WB.3.1.1 Example Watershed Geographic Location, Area, and Physical Characteristics

(Reference Hydrology Manual Section 4.2.1)

Figure WB.3-1 shows the example watershed delineated on USGS topographic maps. The watershed area was measured using a planimeter and recorded on the map. Other relevant information that will be used for calculation of T_l (watershed length, length to centroid, maximum elevation, minimum elevation, and $\overline{n}$) is also recorded on the map. The watershed length and length to centroid were measured along the watercourse. The centroid is the point where approximately 50% of the watershed area is contributing to the watercourse. Length to centroid is measured from the downstream point of the watershed to the centroid. The average of Manning's n values ($\overline{n}$) (described in Section 4.3.5 of the Hydrology Manual) for the watercourse and its tributaries was determined by a field visit.



SOURCE: USGS Valley Center and Rodriguez Mountain Quadrangles. 1988.

Example Watershed Geographic Location and Physical Characteristics

FIGURE

WB.3-1

WB.3.1.2 Example Precipitation and Precipitation Zone Number (Reference Hydrology Manual Section 4.2.2)

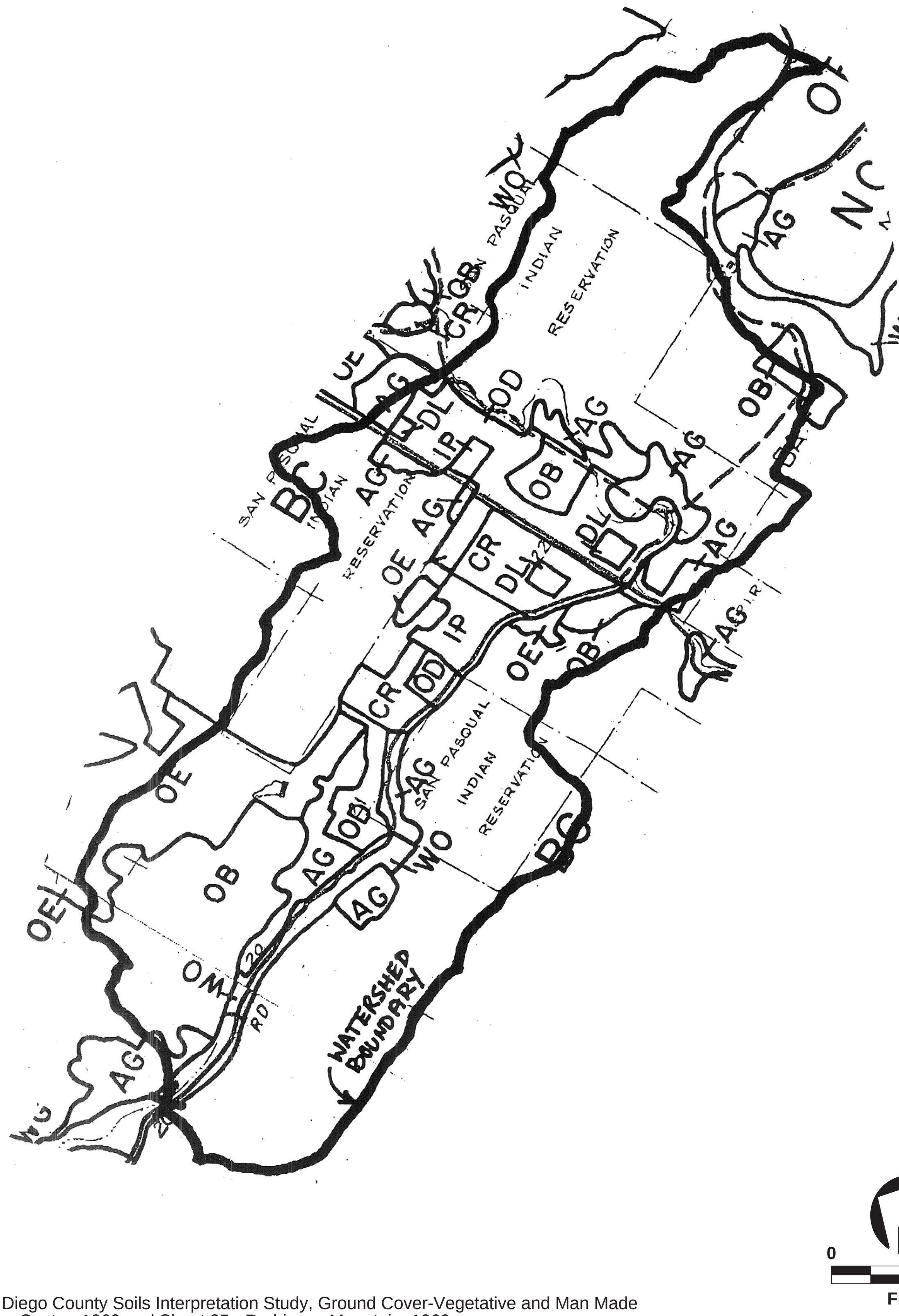
The design storm precipitation values and the PZN for the watershed were determined from the maps provided in Appendix B and Appendix C of the Hydrology Manual, respectively. The 100-year 24-hour storm precipitation (P_{24}) is 8.3 inches, and the 100-year 6-hour storm precipitation (P_6) is 3.9 inches. The PZN is 2.5.

P_6 is within 45% to 65% of P_{24}, therefore no adjustment to P_6 is necessary based on the concepts presented in Section 3.1.3 of the Hydrology Manual. The rainfall depth-area adjustment described in Section 4.1.1.3 of the Hydrology Manual will be performed by the SDUH Peak Discharge Program. The SDUH Peak Discharge Program will also prepare the rainfall distribution and calculate excess rainfall.

WB.3.1.3 Example Runoff Curve Number (Reference Hydrology Manual Section 4.2.3 and 4.2.4)

Figures WB.3-2 and WB.3-3 show NRCS hydrologic ground cover (land use) and NRCS soil groups within the project area, respectively. When translucent vellum with grid ticks is overlain on the maps, the land use/soil group combinations are as shown in Figure WB.3-4. Half-inch grid ticks were used for this study because the watershed is less than 10 square miles in size. Worksheet 4-1 of the Hydrology Manual was used to record the number of grid ticks for each combination. See Appendix WB.A (blank copies are provided in Appendix D of the Hydrology Manual).

The CNs for each land use/soil group combination were determined from Table 4-2 of the Hydrology Manual. For the purpose of this example, the hydrologic condition was assumed to be good, and the crop land was assumed to be straight row crops. For the deciduous orchards, cover during storm periods (winter time) was assumed to be annual grass in good condition.

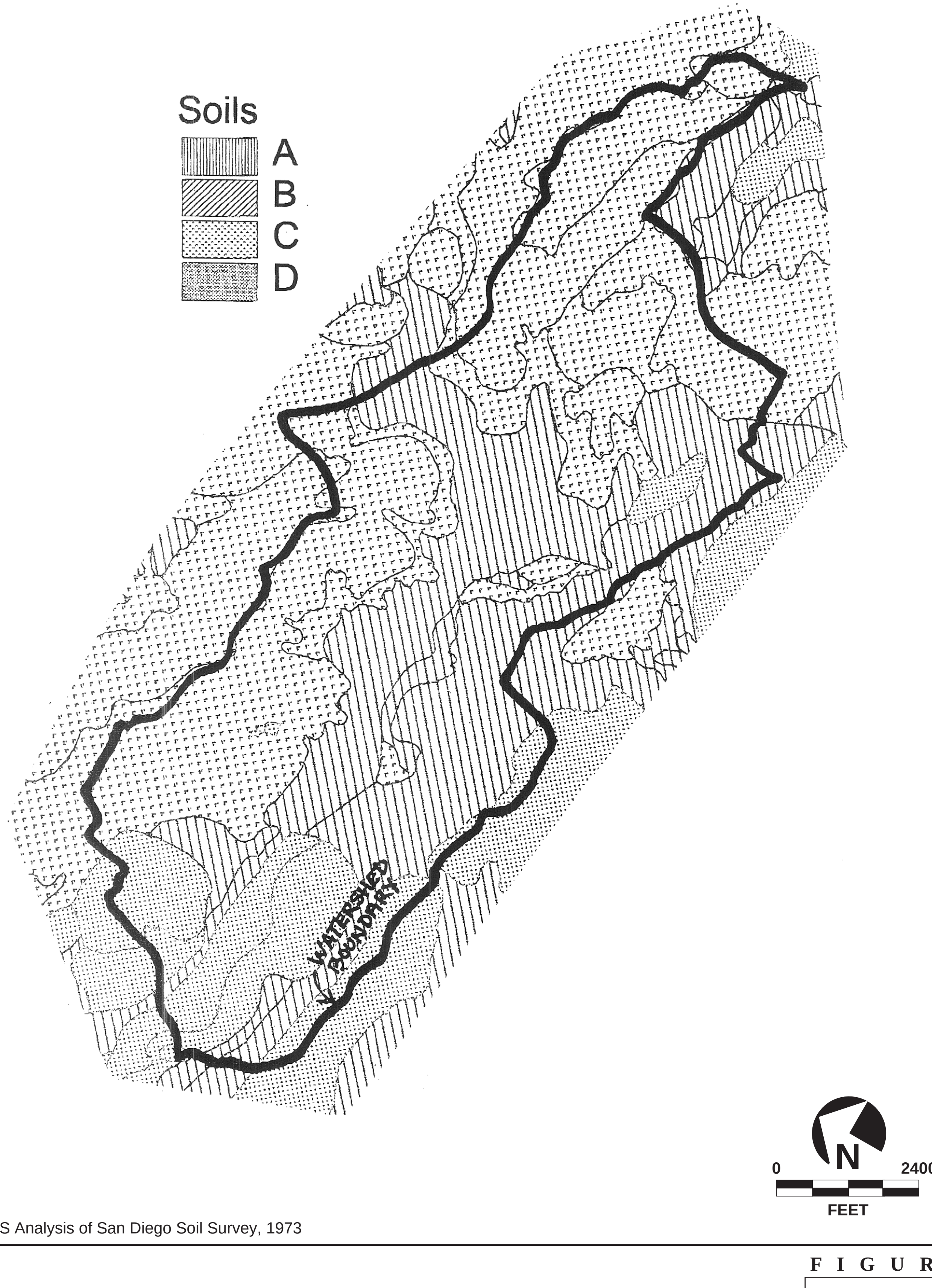


SOURCE: San Diego County Soils Interpretation Study, Ground Cover-Vegetative and Man Made
Sheet 24 - Valley Center, 1969 and Sheet 25 - Rodriquez Mountain, 1969

FIGURE

WB.3-2

Example Watershed Hydrologic Ground Cover

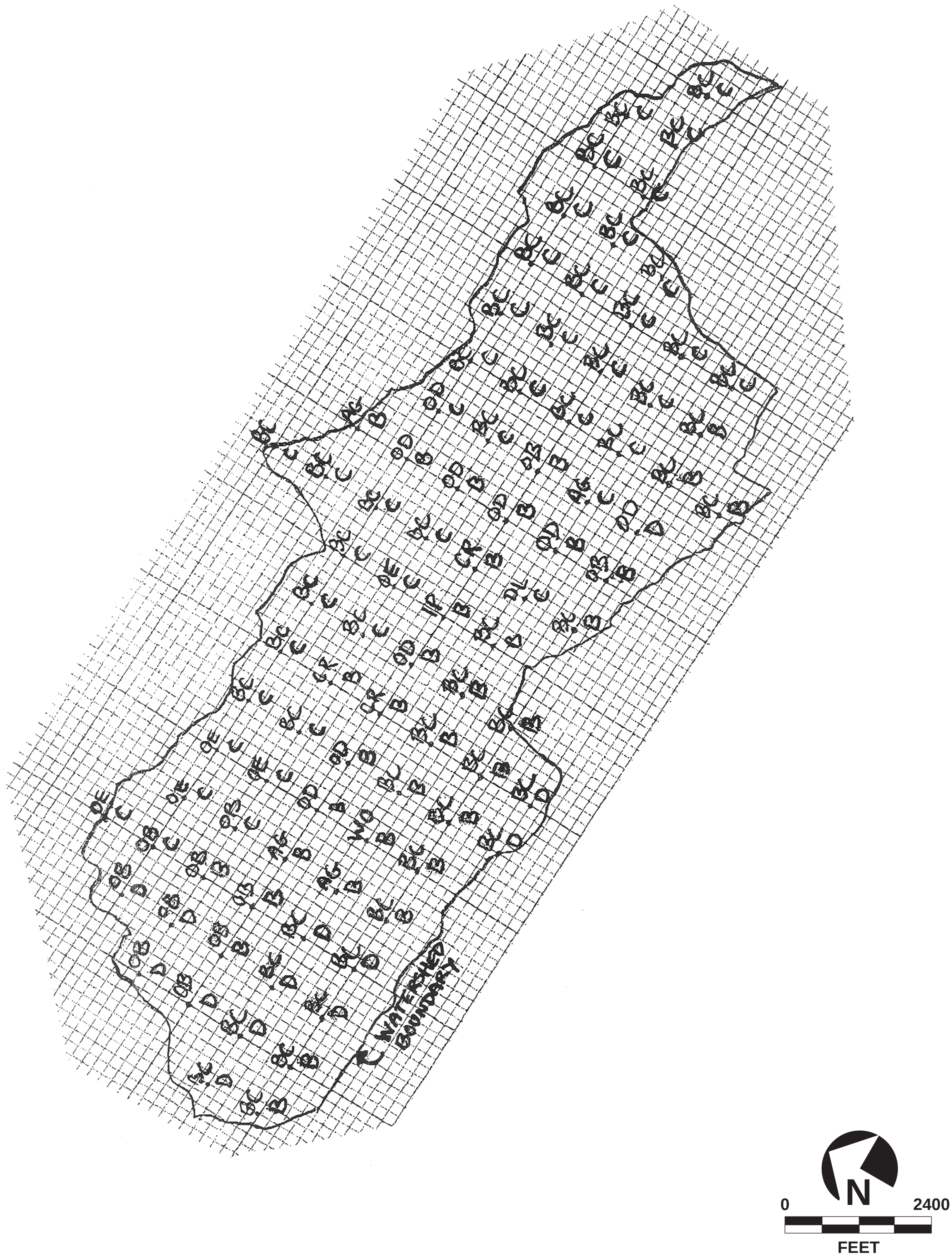


SOURCE: GIS Analysis of San Diego Soil Survey, 1973

FIGURE

WB.3-3

Example Watershed Hydrologic Soils Groups



Example Watershed Grid Tick Overlay

FIGURE

WB.3-4

Calculations for the composite CN were performed using Worksheet 4-2 of the Hydrology Manual. See Appendix WB.A (blank copies are provided in Appendix D of the Hydrology Manual). A spreadsheet set up in the format of Table 4-9 of the Hydrology Manual could also be used for this calculation. The composite CN for the watershed unadjusted for PZN Condition is 69.

No adjustments are being made to this CN for unconnected impervious areas since the amount of developed land in the watershed as shown in Figure WB.3-1 is small. However, the CN must be adjusted for PZN Condition. The PZN adjustment factor is determined using the data provided in Table 4-6 of the Hydrology Manual. From Table 4-6 of the Hydrology Manual, based on the design storm frequency and the PZN, the PZN adjustment factor for this study is 3.0. From Table 4-10 of the Hydrology Manual, the composite CN for the watershed adjusted for PZN Condition is 84.

WB.3.1.4 Example Watershed Lag Time, Time to Peak, and Computation Interval (Reference Hydrology Manual Section 4.3.1)

Corps lag, defined as the elapsed time (in hours) from the beginning of unit effective rainfall to the instant that the summation hydrograph for the point of concentration reaches 50% of ultimate discharge for the watershed is determined using the lag relationship given by the empirical formula presented in Section 4.1.5.2 of the Hydrology Manual (equation 4-17). The watershed length (miles), length to centroid (miles), and $\bar{n}$ are shown in Figure WB.3-1. The watershed slope is the difference in elevation between the high and low points of the watershed (in feet) divided by the watershed length (in miles). Using equation 4-17:

$$T_l \text{ (hours)} = 24\ \bar{n}\ ((L \times L_c) / s^{0.5})^m$$

$$T_l \text{ (hours)} = 24 \times (0.050)\ ((4.05 \times 1.78) / 188^{0.5})^{0.38} = 0.94$$

T_p for the watershed is calculated based on Corps lag using the formula presented in Section 4.1.5.2 of the Hydrology Manual (equation 4-19):

$$T_p = 0.862 \text{ Corps } T_l$$

$$T_p = 0.862 \times 0.94 \text{ hours} = 0.81 \text{ hours}$$

An appropriate computation interval (D) for the NRCS hydrologic method calculations must be selected based on T_p. A small amount of variation is allowable in D, however D should be approximately $0.2T_p$.

For this example:

$$0.2 \text{ (0.81 hours) (60 minutes / hour)} = 9.7 \text{ minutes}$$

A computation interval (D) of 5 minutes will be used.

WB.3.1.5 Example Watershed Peak Discharge Determination Using SDUH Peak Discharge Program

The calculation of peak flow for this study is performed using the SDUH Peak Discharge Program. Worksheet 4-3 of the Hydrology Manual is used to record the input data to the SDUH Peak Discharge Program. See Appendix WB.A (blank copies are provided in Appendix D of the Hydrology Manual). The rainfall depth-area adjustment will be performed by the SDUH Peak Discharge Program. The SDUH Peak Discharge Program will also prepare the rainfall distribution, calculate excess rainfall, and prepare the unit hydrograph ordinates.

From the SDUH Peak Discharge Program, using a watershed area of 3.0 miles, CN of 84, P_6 of 3.9 inches and P_{24} of 8.3 inches, Corps lag of 0.94 hours, and computation interval of 5 minutes, the peak runoff from the watershed for this study is approximately 3,265 cubic feet per second. The SDUH Peak Discharge Program output is provided in Appendix WB.A.

WB.3.2 NRCS Hydrologic Method Example #2, Convolution of Runoff Hydrograph by Hand Computation and Comparison of Results with SDUH Peak Discharge Program and HEC-1

(Reference Hydrology Manual Section 4.3)

This example is a 100-year storm event for a watershed with the following data:

Area = 40.0 square-miles
PZN Adjusted CN = 85.0
P_6 = 3.0 inches
P_{24} = 5.5 inches
Corps Lag = 1.74 hours

P_6 is within 45% to 65% of P_{24}, therefore no adjustment to P_6 is necessary based on the concepts presented in Section 3.1.3 of the Hydrology Manual.

WB.3.2.1 Example Time to Peak and Computation Interval

(Reference Hydrology Manual Section 4.1.5.3)

An appropriate computation interval (D) for the NRCS hydrologic method calculations must be selected based on T_p. A small amount of variation is allowable in D, however D should be approximately $0.2T_p$. Therefore, T_p must be determined for the watershed. T_p can be calculated based on Corps lag using equation 4-19:

$$T_p = 0.862 \text{ Corps } T_l$$

For this study, with Corps lag given as 1.74 hours:

$$T_p = 0.862 \text{ (1.74 hours)} = 1.5 \text{ hours}$$

$$0.2 \text{ (1.5 hours) (60 minutes / hour)} = 18 \text{ minutes}$$

A computation interval (D) of 15 minutes will be used.

WB.3.2.2 Example Precipitation Distribution
(Reference Hydrology Manual Sections 4.1.1 and 4.3.2)

Creation of the 24-hour nested storm rainfall distribution requires rainfall depths for increments of storm duration from the selected computation interval (15 minutes for this study) through 24 hours.

For increments of duration less than 6 hours, total rainfall for the duration shall be computed by calculating the intensity for the duration using the intensity-duration design equation presented in Section 3 of the Hydrology Manual, and multiplying the intensity by the duration. For each duration:

$$I = 7.44\ P_6\ D^{-0.645}$$

and:

$$P = I\ (D/60)$$

For increments of duration between 6 hours and 24 hours, total rainfall depth is interpolated between the 6-hour and 24-hour rainfall values using log-log interpolation (an alternative method is to read from a log-log chart by extending a straight line on log-log paper between the 6-hour and 24-hour rainfall values).

Next, the total rainfall depth for each duration must be adjusted using the appropriate depth-area adjustment values based on the watershed area from Figure 4-2 or Table 4-1 of the Hydrology Manual (the rainfall amount is multiplied by the depth-area adjustment factor). For durations less than 30 minutes, the 30-minute depth area adjustment value is used. For durations greater than 30 minutes and not equal to durations with data available on Table 4-1 of the Hydrology Manual, the depth area adjustment is interpolated by linear interpolation between the surrounding data points on Table 4-1 of the Hydrology Manual (an alternative is to read the data from Figure 4-2 of the Hydrology Manual).

Next, the ordinates of the hyetograph are created using the depth-area adjusted total rainfall amounts. The first ordinate "R(D)" is the depth-area adjusted total rainfall amount for the first time increment. The second ordinate "R(2D) –R(D)" is the depth-area adjusted total rainfall amount for the second time increment minus the depth-area adjusted total rainfall amount for the first time increment. The third ordinate "R(3D) – R(2D)" is the depth-area adjusted total rainfall amount for the third time increment minus depth-area adjusted total rainfall amount for the second time increment, and so on. Note: the sum of the ordinates of the hyetograph should be equal to the depth-area adjusted total rainfall amount for duration = 24 hours (5.269 inches for this study).

The data resulting from these equations are presented in Table WB.3-1.

Table WB.3-1 (Page 1 of 4)

NRCS HYDROLOGIC METHOD EXAMPLE #2 RAINFALL DISTRIBUTION DATA SORTED IN ORDER OF INCREASING DURATION

Duration (minutes)	Precipitation for Duration, P (inches)	Depth Area Adjustment for Duration	Depth-Area Adjusted Precipitation (inches)	Hyetograph Ordinate, R (inches)
15	0.973	0.730	0.710	0.710
30	1.244	0.730	0.908	0.198
45	1.437	0.780	1.121	0.212
60	1.591	0.830	1.321	0.200
75	1.723	0.841	1.448	0.127
90	1.838	0.851	1.564	0.116
105	1.941	0.862	1.673	0.109
120	2.035	0.873	1.776	0.103
135	2.122	0.883	1.874	0.098
150	2.203	0.894	1.969	0.095
165	2.279	0.904	2.061	0.092
180	2.351	0.915	2.151	0.090
195	2.418	0.917	2.218	0.067
210	2.483	0.919	2.282	0.064
225	2.544	0.921	2.344	0.062
240	2.603	0.923	2.404	0.060
255	2.660	0.925	2.462	0.058
270	2.714	0.928	2.518	0.056
285	2.767	0.930	2.572	0.055
300	2.818	0.932	2.625	0.053
315	2.867	0.934	2.677	0.052
330	2.915	0.936	2.728	0.051
345	2.961	0.938	2.777	0.050
360	3.000	0.940	2.820	0.043

Table WB.3-1 Continued (Page 2 of 4)

NRCS HYDROLOGIC METHOD EXAMPLE #2 RAINFALL DISTRIBUTION DATA SORTED IN ORDER OF INCREASING DURATION

Duration (minutes)	Precipitation for Duration, P (inches)	Depth Area Adjustment for Duration	Depth-Area Adjusted Precipitation (inches)	Hyetograph Ordinate, R (inches)
375	3.054	0.940	2.872	0.052
390	3.107	0.941	2.922	0.050
405	3.159	0.941	2.971	0.049
420	3.209	0.941	3.020	0.048
435	3.259	0.941	3.067	0.048
450	3.307	0.942	3.114	0.047
465	3.355	0.942	3.160	0.046
480	3.402	0.942	3.205	0.045
495	3.448	0.942	3.249	0.044
510	3.493	0.943	3.293	0.044
525	3.538	0.943	3.336	0.043
540	3.582	0.943	3.378	0.042
555	3.625	0.943	3.419	0.042
570	3.668	0.944	3.460	0.041
585	3.709	0.944	3.501	0.040
600	3.751	0.944	3.541	0.040
615	3.791	0.944	3.580	0.039
630	3.832	0.945	3.619	0.039
645	3.871	0.945	3.657	0.038
660	3.910	0.945	3.695	0.038
675	3.949	0.945	3.733	0.037
690	3.987	0.946	3.770	0.037
705	4.025	0.946	3.806	0.037
720	4.062	0.946	3.843	0.036

Table WB.3-1 Continued (Page 3 of 4)

NRCS HYDROLOGIC METHOD EXAMPLE #2 RAINFALL DISTRIBUTION DATA SORTED IN ORDER OF INCREASING DURATION

Duration (minutes)	Precipitation for Duration, P (inches)	Depth Area Adjustment for Duration	Depth-Area Adjusted Precipitation (inches)	Hyetograph Ordinate, R (inches)
735	4.099	0.946	3.878	0.036
750	4.135	0.947	3.914	0.035
765	4.171	0.947	3.949	0.035
780	4.207	0.947	3.984	0.035
795	4.242	0.947	4.018	0.034
810	4.277	0.948	4.052	0.034
825	4.311	0.948	4.086	0.034
840	4.345	0.948	4.119	0.033
855	4.379	0.948	4.152	0.033
870	4.412	0.949	4.185	0.033
885	4.446	0.949	4.218	0.033
900	4.478	0.949	4.250	0.032
915	4.511	0.949	4.282	0.032
930	4.543	0.950	4.314	0.032
945	4.575	0.950	4.345	0.031
960	4.606	0.950	4.376	0.031
975	4.638	0.950	4.407	0.031
990	4.669	0.951	4.438	0.031
1005	4.700	0.951	4.468	0.030
1020	4.730	0.951	4.498	0.030
1035	4.761	0.951	4.528	0.030
1050	4.791	0.952	4.558	0.030
1065	4.820	0.952	4.588	0.030
1080	4.850	0.952	4.617	0.029

Table WB.3-1 Continued (Page 4 of 4)

NRCS HYDROLOGIC METHOD EXAMPLE #2 RAINFALL DISTRIBUTION DATA SORTED IN ORDER OF INCREASING DURATION

Duration (minutes)	Precipitation for Duration, P (inches)	Depth Area Adjustment for Duration	Depth-Area Adjusted Precipitation (inches)	Hyetograph Ordinate, R (inches)
1095	4.879	0.952	4.646	0.029
1110	4.908	0.953	4.675	0.029
1125	4.937	0.953	4.704	0.029
1140	4.966	0.953	4.733	0.029
1155	4.994	0.953	4.761	0.028
1170	5.023	0.954	4.789	0.028
1185	5.051	0.954	4.817	0.028
1200	5.079	0.954	4.845	0.028
1215	5.106	0.954	4.873	0.028
1230	5.134	0.955	4.900	0.027
1245	5.161	0.955	4.927	0.027
1260	5.188	0.955	4.955	0.027
1275	5.215	0.955	4.982	0.027
1290	5.242	0.956	5.008	0.027
1305	5.268	0.956	5.035	0.027
1320	5.295	0.956	5.062	0.027
1335	5.321	0.956	5.088	0.026
1350	5.347	0.957	5.114	0.026
1365	5.373	0.957	5.140	0.026
1380	5.399	0.957	5.166	0.026
1395	5.424	0.957	5.192	0.026
1410	5.450	0.958	5.218	0.026
1425	5.475	0.958	5.244	0.026
1440	5.500	0.958	5.269	0.025
			Total:	5.269

Finally, sort the ordinates of the hyetograph into the order of the (2/3, 1/3) distribution. Figure 4-9 of the Hydrology Manual shows the construction of the hyetograph. Table WB.3-2 (in Section WB.3.2.3) shows the ordinates of the hyetograph for this study sorted in the order of the (2/3, 1/3) distribution. The first ordinate (calculated above, the depth-area adjusted incremental rainfall amount for the first time increment) is the peak rainfall ordinate. This peak rainfall ordinate occurs at hour 16.0 of the 24-hour storm. The second rainfall ordinate (calculated above) occurs at 16.0 hours – 1D, the third rainfall ordinate (calculated above) occurs at 16.0 hours – 2D, and the fourth rainfall ordinate (calculated above) occurs at 16.0 hours + 1D. The sequence continues alternating two ordinates to the left and one ordinate to the right (see Figure 4-9 of the Hydrology Manual).

WB.3.2.3 Example Effective Rainfall
(Reference Hydrology Manual Sections 4.1.3 and 4.3.3)

Excess rainfall is calculated using equation 4-4.

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

where:

$$S = 1000/CN - 10$$

Because equation 4-4 is subject to the limitation, $P \geq 0.2S$, calculation of excess rainfall based on the ordinates of the hyetograph (which are incremental rainfall amounts) will result in underestimation of excess rainfall because the incremental rainfall amounts are small. Excess rainfall must be calculated for a cumulative rainfall series. A cumulative rainfall series is created by summing the ordinates of the hyetograph. This must be performed after the ordinates have been sorted into the (2/3, 1/3) distribution. The last ordinate of the series should be equal to the excess runoff from the depth-area adjusted incremental rainfall amount for duration = 24 hours (5.269 inches for this study). Finally, incremental amounts of excess rainfall are created from the cumulative series. The data resulting from these equations are presented in Table WB.3-1.

Table WB.3-2 (Page 1 of 4)

NRCS HYDROLOGIC METHOD EXAMPLE #2 CALCULATED EXCESS RAINFALL SORTED IN ORDER OF (2/3, 13/) RAINFALL DISTRIBUTION

Time (minutes)	Hyetograph Ordinate (inches)	Cumulative Rainfall (inches)	Cumulative Excess Rainfall (inches)	Incremental Excess Rainfall (inches)
15	0.025	0.025	0.000	0.000
30	0.026	0.051	0.000	0.000
45	0.026	0.077	0.000	0.000
60	0.026	0.103	0.000	0.000
75	0.026	0.129	0.000	0.000
90	0.026	0.155	0.000	0.000
105	0.027	0.182	0.000	0.000
120	0.027	0.209	0.000	0.000
135	0.027	0.236	0.000	0.000
150	0.027	0.264	0.000	0.000
165	0.028	0.291	0.000	0.000
180	0.028	0.319	0.000	0.000
195	0.028	0.347	0.000	0.000
210	0.028	0.376	0.000	0.000
225	0.029	0.404	0.001	0.001
240	0.029	0.433	0.003	0.002
255	0.029	0.463	0.006	0.003
270	0.030	0.492	0.010	0.004
285	0.030	0.522	0.015	0.005
300	0.030	0.552	0.020	0.005
315	0.031	0.583	0.027	0.006
330	0.031	0.614	0.034	0.007
345	0.031	0.645	0.042	0.008
360	0.032	0.677	0.050	0.009

Table WB.3-2 Continued (Page 2 of 4)

NRCS HYDROLOGIC METHOD EXAMPLE #2 CALCULATED EXCESS RAINFALL SORTED IN ORDER OF (2/3, 13/) RAINFALL DISTRIBUTION

Time (minutes)	Hyetograph Ordinate (inches)	Cumulative Precipitation (inches)	Cumulative Excess Rainfall (inches)	Incremental Excess Rainfall (inches)
375	0.032	0.709	0.060	0.010
390	0.033	0.742	0.070	0.010
405	0.033	0.775	0.081	0.011
420	0.033	0.808	0.093	0.012
435	0.034	0.842	0.106	0.013
450	0.034	0.877	0.120	0.014
465	0.035	0.912	0.134	0.015
480	0.035	0.947	0.150	0.015
495	0.036	0.984	0.166	0.016
510	0.037	1.020	0.183	0.017
525	0.037	1.058	0.201	0.018
540	0.038	1.096	0.220	0.019
555	0.039	1.134	0.240	0.020
570	0.039	1.174	0.261	0.021
585	0.040	1.214	0.283	0.022
600	0.041	1.255	0.305	0.023
615	0.042	1.298	0.329	0.024
630	0.043	1.340	0.354	0.025
645	0.044	1.385	0.381	0.026
660	0.045	1.430	0.408	0.027
675	0.047	1.476	0.437	0.029
690	0.048	1.524	0.467	0.030
705	0.049	1.573	0.499	0.032
720	0.050	1.624	0.532	0.033

Table WB.3-2 Continued (Page 3 of 4)

NRCS HYDROLOGIC METHOD EXAMPLE #2 CALCULATED EXCESS RAINFALL SORTED IN ORDER OF (2/3, 13/) RAINFALL DISTRIBUTION

Time (minutes)	Hyetograph Ordinate (inches)	Cumulative Precipitation (inches)	Cumulative Excess Rainfall (inches)	Incremental Excess Rainfall (inches)
735	0.043	1.666	0.560	0.028
750	0.050	1.716	0.594	0.034
765	0.052	1.768	0.630	0.036
780	0.053	1.821	0.667	0.037
795	0.056	1.877	0.706	0.040
810	0.058	1.935	0.748	0.041
825	0.062	1.997	0.793	0.045
840	0.064	2.061	0.840	0.047
855	0.090	2.151	0.907	0.067
870	0.092	2.243	0.977	0.070
885	0.098	2.341	1.053	0.076
900	0.103	2.444	1.134	0.081
915	0.116	2.560	1.227	0.093
930	0.127	2.687	1.329	0.103
945	0.212	2.900	1.504	0.175
960	0.198	3.098	1.671	0.166
975	0.710	3.808	2.287	0.616
990	0.200	4.008	2.465	0.178
1005	0.109	4.117	2.563	0.097
1020	0.095	4.212	2.648	0.085
1035	0.067	4.279	2.708	0.061
1050	0.060	4.338	2.762	0.054
1065	0.055	4.393	2.812	0.049
1080	0.051	4.444	2.858	0.046

Table WB.3-2 Continued (Page 4 of 4)

NRCS HYDROLOGIC METHOD EXAMPLE #2 CALCULATED EXCESS RAINFALL SORTED IN ORDER OF (2/3, 13/) RAINFALL DISTRIBUTION

Time (minutes)	Hyetograph Ordinate (inches)	Cumulative Precipitation (inches)	Cumulative Excess Rainfall (inches)	Incremental Excess Rainfall (inches)
1095	0.052	4.495	2.905	0.047
1110	0.048	4.544	2.949	0.044
1125	0.046	4.589	2.991	0.042
1140	0.044	4.633	3.031	0.040
1155	0.042	4.675	3.069	0.038
1170	0.040	4.715	3.105	0.037
1185	0.038	4.753	3.140	0.035
1200	0.037	4.790	3.174	0.034
1215	0.036	4.826	3.207	0.033
1230	0.035	4.861	3.239	0.032
1245	0.034	4.894	3.270	0.031
1260	0.033	4.927	3.301	0.030
1275	0.032	4.959	3.330	0.029
1290	0.031	4.990	3.359	0.029
1305	0.030	5.021	3.387	0.028
1320	0.030	5.050	3.415	0.028
1335	0.029	5.080	3.442	0.027
1350	0.029	5.108	3.468	0.026
1365	0.028	5.136	3.494	0.026
1380	0.027	5.164	3.520	0.026
1395	0.027	5.191	3.545	0.025
1410	0.027	5.217	3.569	0.025
1425	0.026	5.243	3.594	0.024
1440	0.026	5.269	3.617	0.024
			Total:	3.617

WB.3.2.4 Example Unit Hydrograph Ordinates
(Reference Hydrology Manual Sections 4.1.3 and 4.3.3)

The unit hydrograph ordinates are created based on the T_p and the unit hydrograph q_p for the study area. T_p was calculated above based on Corps lag (see Section WB.3.2.1). The unit hydrograph q_p is then calculated using equation 4-10:

$$q_p = \frac{K_s\ A\ Q_a}{T_p}$$

where:

K_s = 484, a constant reflecting both the conversion of units and the shape of the hydrograph
Q_a = 1 inch of effective runoff

The watershed area for this study is 40.0 square miles and T_p is 1.5 hours. Using equation 4-10:

$$q_p = (484)(40.0)(1.0) / 1.5 = 12{,}907$$

Use T_p and q_p to set up the unit hydrograph ordinates t/T_p and q/q_p. The time increment (t) for unit hydrograph ordinates must be the same duration as the period of effective rainfall or computation interval (D) selected for the rainfall ordinates. The computation interval for this example is 15 minutes. For multiples of t, t/T_p is computed until $t/T_p = 5$. For each t/T_p, the corresponding q/q_p is found from Table 4-7 of the Hydrology Manual. For values of t/T_p that are not given on Table 4-7 of the Hydrology Manual, the corresponding values of q/q_p are interpolated by linear interpolation from the nearest values from Table 4-7 of the Hydrology Manual (an alternative is to read the values from Figure 4-4 of the Hydrology Manual). Table WB.3-3 presents the unit hydrograph ordinates for this example.

Table WB.3-3

NRCS HYDROLOGIC METHOD EXAMPLE #2 UNIT HYDROGRAPH ORDINATES

Time (minutes)	t/T_p	q/q_p	q (cfs/inch)
15	0.167	0.079	1020
30	0.333	0.226	2917
45	0.500	0.470	6066
60	0.667	0.772	9964
75	0.833	0.948	12236
90	1.000	1.000	12907
105	1.167	0.948	12236
120	1.333	0.836	10790
135	1.500	0.680	8777
150	1.667	0.490	6324
165	1.833	0.372	4801
180	2.000	0.280	3614
195	2.167	0.218	2814
210	2.333	0.168	2168
225	2.500	0.127	1639
240	2.667	0.097	1252
255	2.833	0.074	955
270	3.000	0.055	710
285	3.167	0.042	542
300	3.333	0.033	426
315	3.500	0.025	323
330	3.667	0.019	245
345	3.833	0.014	181
360	4.000	0.011	142
375	4.167	0.009	116
390	4.333	0.007	90
405	4.500	0.005	65
420	4.667	0.003	39
435	4.833	0.002	26
450	5.000	0.000	0

**WB.3.2.5 Example Convolution of Unit Hydrograph
(Reference Hydrology Manual Section 4.3.4)**

To perform the NRCS hydrologic method calculation, a table is set up with the unit hydrograph ordinates in rows and incremental excess rainfall ordinates in columns. The table is presented in Appendix WB.B. Convolution of the unit hydrograph is performed as follows:

1. The effective rainfall depth for the first unit time period is multiplied by each unit hydrograph ordinate q to determine the flood hydrograph which would result from that increment of effective rainfall.
2. The above process is repeated for each succeeding effective rainfall depth advancing the resultant flood hydrographs one unit time period for each cycle.
3. The flow ordinates found in the steps above are summed across the rows to determine the average flow ordinates per unit time period for the design storm flood hydrograph.

The average flow ordinates that are found in step 3 are ordinates of the runoff hydrograph. The peak runoff from the watershed for this study is approximately 18,545 cubic feet per second, and occurs at time 1050 minutes (17.5 hours).

WB.3.2.6 Comparison of Results of Hand Computation, SDUH Peak Discharge Program, and HEC-1

The data for this study was also processed using the SDUH Peak Discharge Program and HEC-1 to compare the peak runoff output from each method. The SDUH Peak Discharge Program output, and the HEC-1 input and output are provided in Appendix WB.C.

HEC-1 requires NRCS lag as the input parameter TLAG that is used with the NRCS hydrologic method calculations (USACE, 1990).

NRCS lag is determined based on T_p using the equation 4-20:

$$\text{NRCS } T_l = T_p - D/2$$

For this study, with T_p equal to 1.5 hours and d equal to 15 minutes (0.25 hours):

$$\text{NRCS } T_l = 1.5 \text{ hours} - (0.25 \text{ hours} / 2) = 1.375 \text{ hours}$$

Table WB.3-4 presents the peak discharge output results of the study based on hand computation, SDUH Peak Discharge Program, and HEC-1.

Table WB.3-4

COMPARISON OF STUDY PEAK DISCHARGE OUTPUT RESULTS FROM HAND COMPUTATION, SDUH PEAK DISCHARGE PROGRAM, AND HEC-1

Study Method	Peak Runoff (cfs)
Hand Computation	18,545
SDUH Peak Discharge Program	18,544
HEC-1	18,512

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WB.4 WORKBOOK EXAMPLES FOR HYDROLOGY MANUAL SECTION 5 EROSION AND SEDIMENTATION

WB.4.1 EXAMPLE SEDIMENTATION YIELD CALCULATIONS USING THE UNIVERSAL SOIL LOSS EQUATION

(Reference Hydrology Manual Section 5.2)

The project is a 20-acre site located in Fallbrook with a soil classification designation of Sandy Loam (FaC) with 20% natural open space area to remain and 80% to be developed. The average slope of the open space is 16% and the developed area will be 1%. Developed area will be filled with import soil (suitable) and is anticipated to be Las Flores Loamy Fine Sand. The distances traveled for the open space and developed areas are 1,100 feet and 120 feet (respectively).

A_s = RKLsCP (USLE)

<u>R Value</u>

Based on a 2-year, 6-hour storm event P = 1.3 inches (interpolated)

Based on Figure 5-2 of the Hydrology Manual, R = 29.5

<u>K Factor</u>

Using soil erodibility information from Table 5-2 of the Hydrology Manual, verified against San Diego soil survey and current soils report;

Open space ~ Sandy Loam (FAC) <u>K = .28</u>
Developed ~ Las Flores Loamy Fine Sand <u>K = .15</u>

Ls Factor

Based on Figure 5-5 of the Hydrology Manual, open space area is 16% slope and 1,100 feet

Ls = 4.7

Developed area with 1% slope and average T_t for each lot is 120 feet

Ls = 0.13

C Factor

Based on site observation, the open space is generally comprised of waist-high weeds (0.5 meters), with bushes being the same height. The bushes hide approximately 25% of the area, from a bird's-eye perspective. The total vegetative cover is estimated at 60%. There is no apparent grass between the weeds or brush (Table 5-3 of the Hydrology Manual).

C = 0.082 (for open space)

C = 1.0 for developed area during construction (no vegetation)

P Factor

P = 1.0

No tillage, cross-slope farming or contour strip cropping.

Determine Sedimentation Yield

Open Space:

A_s = RKLsCP = (29.5) (.16) (4.7) (.082) (1.0) = 1.82 tons/acre/year

Soil density estimated @ 116 lb/ft^3 for on-site soils

$$\text{Volume}_{os} = 1.82 \text{ tons/acre/year} \times \frac{2000 \text{ pounds}}{\text{ton}} \times \frac{\text{ft}^3}{116 \text{ pounds}} \times 20 \text{ acres} (20\%) = \boxed{125.5 \text{ ft}^3}$$

Developed Area:

A_s = RKLsCP = (29.5) (.15) (.13) (1.0) (1.0) = 0.58 tons/acre/year

Soil density of import soil estimated @ 123 lb/ft^3

$$\text{Volume}_{DA} = .58 \text{ tons/acre/year x } \frac{2000 \text{ pounds}}{\text{ton}} \text{ x } \frac{\text{ft}^3}{123 \text{ pounds}} \text{ x } 20 \text{ acres } (80\%) = \boxed{151.0 \text{ ft}^3}$$

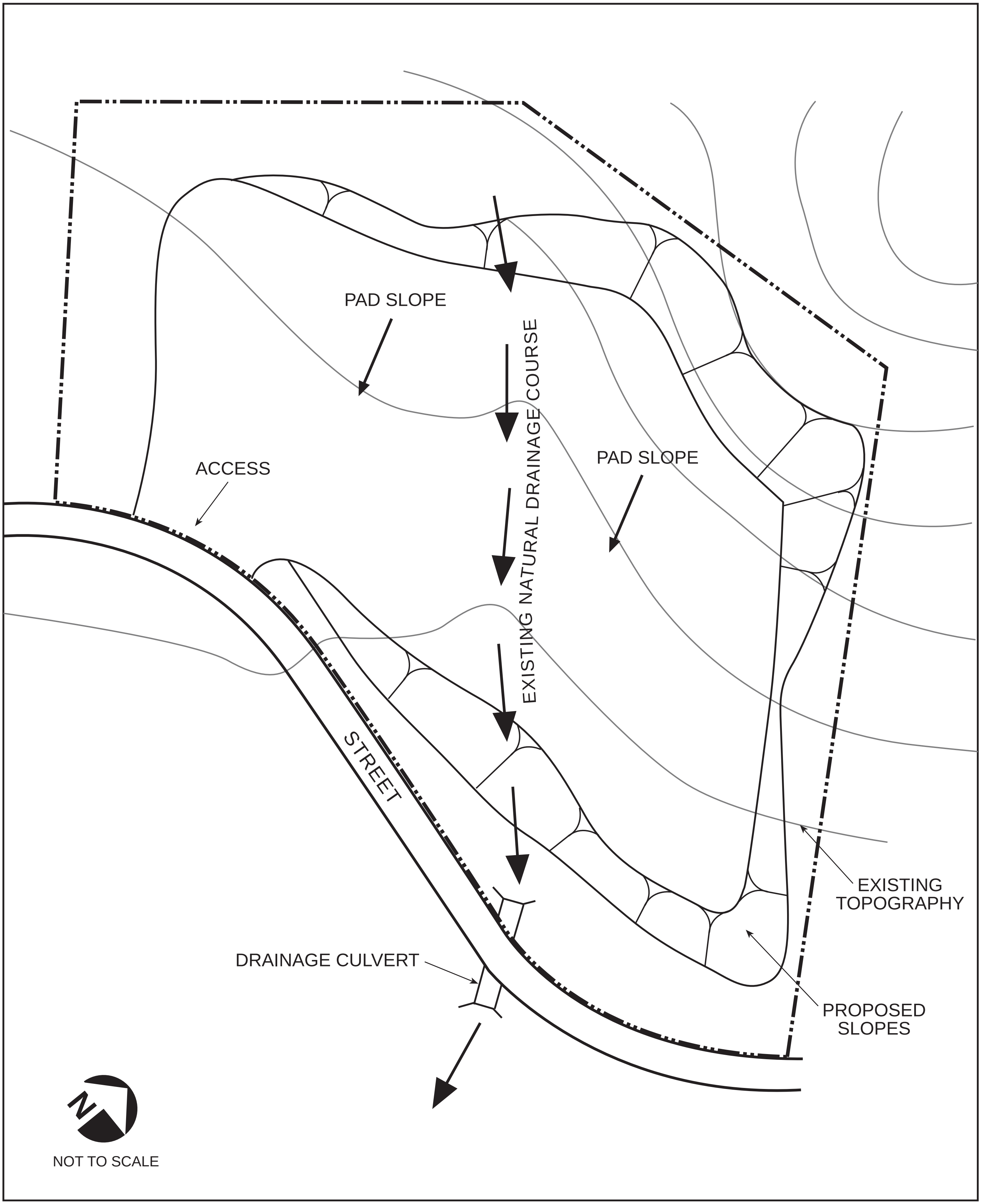
Total volume to be captured per year = $\boxed{151 \text{ ft}^3}$

125 + 151 = $\boxed{276 \text{ ft}^3 = \text{Volume Total}}$

WB.4.2 EXAMPLE EROSION CONTROL PLAN
(Reference Hydrology Manual Section 5.4)

To demonstrate how erosion control devices are prepared, an example project known as "Project A" is provided (see Figure WB.4-1). This project fronts an improved public street and the site will be graded to support a building. The site contains variable slopes that are currently vegetated. The site also includes a natural drainage course crossing the property. Special consideration must be given to the natural drainage course. If earthwork operators disturb the site by removing existing vegetation (scarification) and a rainstorm occurs, the ditch could discharge across the site and erode the site. Stormwater from the natural channel should be collected, conveyed, and discharged across the site during all phases of the project. Based on the size of the project, runoff potential from the drainage course, and proximity to a major culvert crossing, a temporary desiltation basin may be warranted. Berms should be installed at the top of slope to ensure water is not directed over the slopes. Slopes should be planted or hydroseeded after they are manufactured. Energy dissipaters (riprap) should be installed at the end of culverts to slow exiting water to a nonerosive velocity. For an example erosion control plan for "Project A," refer to Figure WB.4-2.

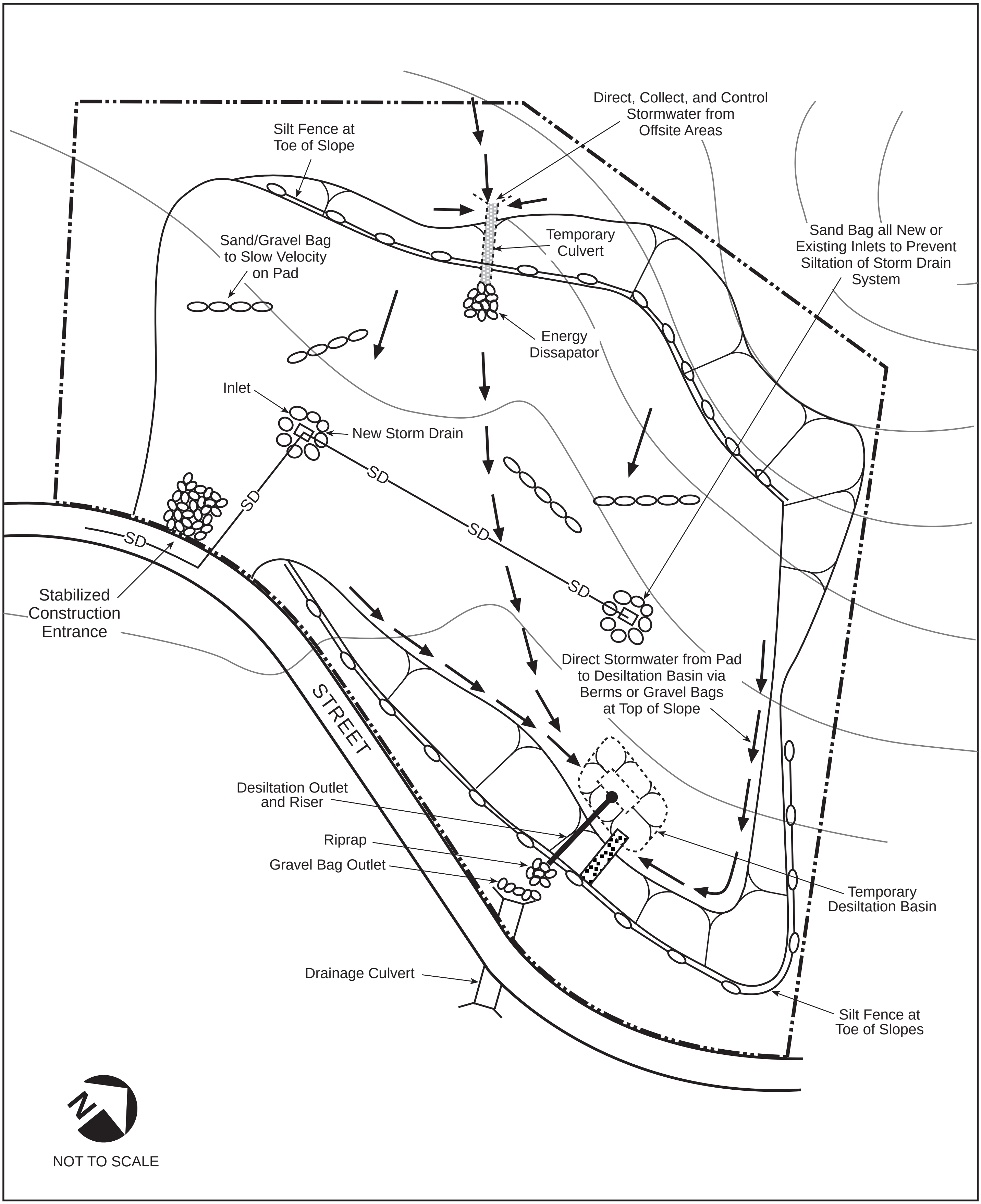
Erosion control plans are frequently prepared for large developments such as subdivisions. Figure WB.4-3 provides an example of erosion control measures for building pads on residential lots. Please note gravel bags have been installed around the proposed curb inlets to prevent siltation of storm drain infrastructure during construction. The bags installed along the street also slow stormwater to prevent erosion. Construction vehicles can maneuver on the street by weaving around the bags. Make sure that the plan shows the use of straw waddles rather than silt fences.



FIGURE

WB. 4-1

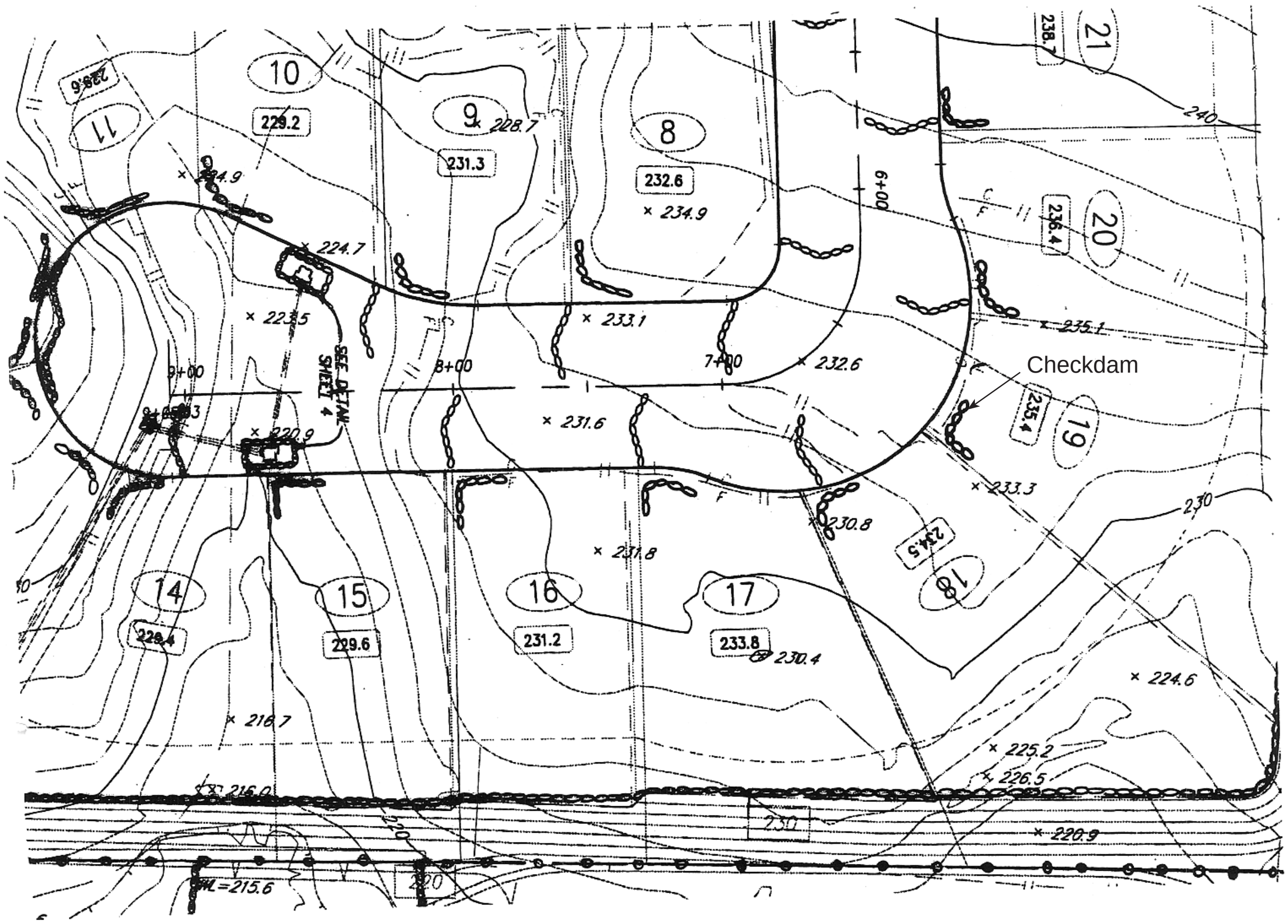
Example Project "A"



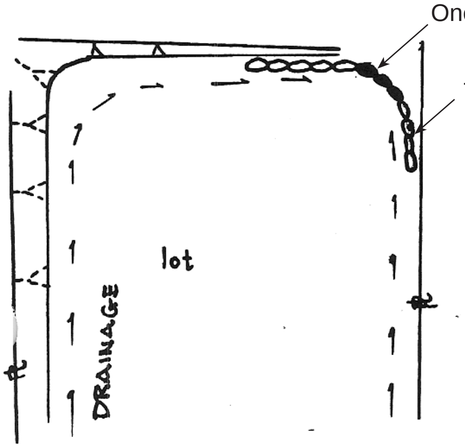
Erosion Control Plan for Project "A"

FIGURE

WB. 4-2



Checkdam



NOT TO SCALE

FIGURE

WB. 4-3

Erosion Control Plan for a Subdivision

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WB.5 WORKBOOK EXAMPLES FOR HYDROLOGY MANUAL SECTION 6 RATIONAL METHOD HYDROGRAPH PROCEDURE

WB.5.1 EXAMPLE HYDROGRAPH DEVELOPMENT
(Reference Hydrology Manual Section 6.2)

The following example demonstrates the development of a hydrograph from Rational Method (RM) study results using the procedure presented in this section. The example drainage area is a 40-acre drainage area with a runoff coefficient of 0.90. A RM study of the drainage area was performed for the 100-year 6-hour storm event. The 100-year 6-hour rainfall (P_6) for the drainage area is 3.0 inches. The RM study results are as follows:

Time of concentration (T_c) = 8.0 minutes
Peak discharge (Q) = 210.1 cfs

The number of rainfall blocks (N) in the rainfall distribution is determined by dividing the duration of the storm (360 minutes) by T_c,:

$$N = 360 / 8.0 = 45$$

The peak discharge, Q_N for each block is calculated using equation 6-5 from Section 6.2.2 of the Hydrology Manual:

$$Q_N = 60\ CAP_N/T_c \text{ (cfs)}$$

Equations 6-2 and 6-3 from Section 6.2.1 of the Hydrology Manual are used to determine P_N for equation 6-5:

$$P_{T(N)} = 0.124\ P_6\ (NT_c)^{0.355}$$

$$P_N = P_{T(N)} - P_{T(N-1)}$$

The data resulting from these equations are presented in Table WB.5-1. These data are calculated for the rainfall blocks sorted in order from N = 1 to N = 45, and are shown in that order in Table WB.5-1. For the rainfall distribution, the rainfall at block N = 1, ($1T_c$), is centered at 4 hours, the rainfall at block N = 2, ($2T_c$), is centered at 4 hours – $1T_c$, the rainfall at block N = 3, ($3T_c$), is centered at 4 hours – $2T_c$, and the rainfall at at block N = 4, ($4T_c$), is centered at 4 hours + $1T_c$. The sequence continues alternating two blocks to the left and one block to the right (see Figure 6-2 of the Hydrology Manual). Table WB.5-2 shows the P_N and Q_N data arranged in the order of the rainfall distribution. The $P_{T(N)}$ data are not shown in Table WB.5-2 because calculation of $P_{T(N)}$ is an intermediate step in the process that is necessary only for calculation of P_N. The time that corresponds to the peak discharge is added to the table. The time corresponding to the peak discharge for block N = 1 is 4 hours + ½T_c, the time corresponding to the peak discharge for block N = 2 is 4 hours – ½T_c, the time corresponding to the peak discharge for block N = 3 is 4 hours – 1½T_c, and the time corresponding to the peak discharge for block N = 4 is 4 hours + 1½T_c. The sequence continues alternating two ordinates to the left and one ordinate to the right (see Figure 6-3 of the Hydrology Manual). Because the hydrograph must begin and end with zero, start and end values of zero have been inserted into the table for time equal to zero (start time) and time equal to 6 hours + ½T_c (end time).

Table WB.5-1

EXAMPLE CALCULATED DATA SORTED WITH RAINFALL BLOCKS IN NUMERICAL ORDER

N	$P_{T(N)}$ (inches)	P_N (inches)	Q_N (cfs)
1	0.78	0.78	210.1
2	1.00	0.22	58.6
3	1.15	0.15	41.6
4	1.27	0.12	33.4
5	1.38	0.10	28.3
6	1.47	0.09	24.9
7	1.55	0.08	22.3
8	1.63	0.08	20.4
9	1.70	0.07	18.8
10	1.76	0.06	17.5
11	1.82	0.06	16.4
12	1.88	0.06	15.4
13	1.93	0.05	14.6
14	1.99	0.05	13.9
15	2.04	0.05	13.3
16	2.08	0.05	12.7
17	2.13	0.05	12.2
18	2.17	0.04	11.8
19	2.21	0.04	11.4
20	2.25	0.04	11.0
21	2.29	0.04	10.6
22	2.33	0.04	10.3
23	2.37	0.04	10.0
24	2.40	0.04	9.7
25	2.44	0.04	9.5
26	2.47	0.03	9.2
27	2.51	0.03	9.0
28	2.54	0.03	8.8

Table WB.5-1 (Continued)

EXAMPLE CALCULATED DATA SORTED WITH RAINFALL BLOCKS IN NUMERICAL ORDER

N	$P_{T(N)}$ (inches)	P_N (inches)	Q_N (cfs)
29	2.57	0.03	8.6
30	2.60	0.03	8.4
31	2.63	0.03	8.2
32	2.66	0.03	8.1
33	2.69	0.03	7.9
34	2.72	0.03	7.7
35	2.75	0.03	7.6
36	2.78	0.03	7.5
37	2.80	0.03	7.3
38	2.83	0.03	7.2
39	2.86	0.03	7.1
40	2.88	0.03	7.0
41	2.91	0.03	6.9
42	2.93	0.02	6.7
43	2.96	0.02	6.6
44	2.98	0.02	6.5
45	3.01	0.02	6.4

Table WB.5-2

EXAMPLE CALCULATED DATA ARRANGED BASED ON THE (2/3, 1/3) RAINFALL DISTRIBUTION

N	P_N (inches)	Q_N (cfs)	Time (hours)
-	0.00	0.0	0
45	0.02	6.4	0.07
44	0.02	6.5	0.20
42	0.02	6.7	0.33
41	0.03	6.9	0.47
39	0.03	7.1	0.60
38	0.03	7.2	0.73
36	0.03	7.5	0.87
35	0.03	7.6	1.00
33	0.03	7.9	1.13
32	0.03	8.1	1.27
30	0.03	8.4	1.40
29	0.03	8.6	1.53
27	0.03	9.0	1.67
26	0.03	9.2	1.80
24	0.04	9.7	1.93
23	0.04	10.0	2.07
21	0.04	10.6	2.20
20	0.04	11.0	2.33
18	0.04	11.8	2.47
17	0.05	12.2	2.60
15	0.05	13.3	2.73
14	0.05	13.9	2.87

Table WB.5-2 (Continued)

EXAMPLE CALCULATED DATA ARRANGED BASED ON THE RAINFALL DISTRIBUTION

N	P_N (inches)	Q_N (cfs)	Time (hours)
12	0.06	15.4	3.00
11	0.06	16.4	3.13
9	0.07	18.8	3.27
8	0.08	20.4	3.40
6	0.09	24.9	3.53
5	0.10	28.3	3.67
3	0.15	41.6	3.80
2	0.22	58.6	3.93
1	0.78	210.1	4.07
4	0.12	33.4	4.20
7	0.08	22.3	4.33
10	0.06	17.5	4.47
13	0.05	14.6	4.60
16	0.05	12.7	4.73
19	0.04	11.4	4.87
22	0.04	10.3	5.00
25	0.04	9.5	5.13
28	0.03	8.8	5.27
31	0.03	8.2	5.40
34	0.03	7.7	5.53
37	0.03	7.3	5.67
40	0.03	7.0	5.80
43	0.02	6.6	5.93
-	0.00	0.0	6.07

The values of Q_N in Table WB.5-2 are the ordinates of the overall hydrograph. The overall hydrograph has its peak at 4 hours plus ½ of the T_c. The total volume under the hydrograph is determined using equation 6-1:

$$VOL = CP_6A$$

The total volume under the example hydrograph in acre-inches is:

$$VOL = (0.90)(3.0)(40) = 108 \text{ acre-inches}$$

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APPENDIX WB.A

WORKSHEETS AND SDUH PEAK DISCHARGE PROGRAM OUTPUT FOR NRCS HYDROLOGIC METHOD EXAMPLE #1

WORKSHEET 4-1 NRCS HYDROLOGIC METHOD EXAMPLE NO. 1 (name of project) **Land Use Worksheet**

DATE / BY		HYDROLOGIC CONDITION											
		GOOD 3				FAIR 2				POOR 1			
		A	B	C	D	A	B	C	D	A	B	C	D
FALLOW STRAIGHT ROW	CR												
ROW CROPS STRAIGHT ROW	CR		3				N/A						
ROW CROPS CONTOURED	CR						N/A						
SMALL GRAIN STRAIGHT ROW	CR						N/A						
SMALL GRAIN CONTOURED	CR						N/A						
CLOSE SEEDED STRAIGHT	CR						N/A						
CLOSE SEEDED CONTOURED	CR						N/A						
IRRIGATED PASTURE	IP		1										
WATER SURFACES (DURING FLOODS)	WA						N/A				N/A		
ORCHARDS EVERGREEN	OE			5									
ORCHARDS DECIDUOUS*	OD		7	1	1								
VINEYARDS	VY												
URBAN LOW DENSITY	DL		N/A					1			N/A		
URBAN MEDIUM DENSITY	DL		N/A								N/A		
URBAN HIGH DENSITY	DL		N/A								N/A		
COMMERCIAL INDUSTRIAL	DL		N/A								N/A		
ANNUAL GRASS	AG		3	1									
BROADLEAF CHAPARRAL	BC		15	32	8								
MEADOW	ME												
NARROWLEAF CHAPARRAL	NC		N/A										
OPEN BRUSH	OB		5	2	4								
PERENNIAL GRASS	PG												
WOODLAND GRASS	WG												
WOODS (WOODLAND)	WO		1										
BARREN	BA		N/A								N/A		
TURF	TU												
FARMSTEADS	FS		N/A								N/A		
ROADS (DIRT)	RD		N/A								N/A		
ROADS (HARD SURFACE)	RD		N/A								N/A		

*For deciduous orchards, select the CN that applies to the land use or the kind and condition of cover during storm periods (winter time). For example, select annual grass CN values for annual grass or grass legume cover. If orchards are kept bare by disking or through the use of herbicides, use fallow CNs.

WORKSHEET 4-2 NRCS HYDROLOGIC METHOD EXAMPLE NO. 1 (name of project) **Curve Number Worksheet**

RUNOFF CURVE NUMBER (for PZN Condition = 2.0) CN_2:

column 1	column 2	column 3	column 4	column 5	column 6
GROUND COVER/ LAND USE	HYDROLOGIC CONDITION (field in-spection)	SOIL GROUP	CN_2 From Hydrology Manual, Table 4-2	FRACTION OF AREA A_i/A	PARTIAL CN_2 $CN_2 \times A_i/A$
CR - Row Crops Straight Row	good	B	78	0.03	2.60
IP - Irrigated Pasture	good	B	58	0.01	0.64
OD - Orchards Deciduous*	good	B C D	61 74 80	0.08 0.01 0.01	4.74 0.82 0.89
DL - Urban Low Density	fair	C	84	0.01	0.93
AG - Annual Grass	good	B C	61 74	0.03 0.01	2.03 0.82
BC - Broadleaf Chaparral	good	B C D	57 71 78	0.17 0.36 0.09	9.50 25.24 6.93
OE - Orchards Evergreen	good	C	72	0.06	4.00
OB - Open Brush	good	B C D	63 75 81	0.06 0.02 0.04	3.50 1.67 3.60
WO - Woodland	good	B	55	0.01	0.61
			Sums =	1.000	68.52

For entire basin CN_2 = 69

* CNs for annual grass were used to represent actual cover expected for this land during storm periods (winter time).

WORKSHEET 4-3 NRCS HYDROLOGIC METHOD EXAMPLE NO. 1 **Peak Discharge Computation**
(name of project)

*****For use with NRCS Hydrologic Method Computations*****

Items in boxes are required input parameters for the SDUH Peak Discharge Program.

Computed by: ENGINEER Date: 5/30/03

Project Identification (Drainage Area Name): EXAMPLE NO. 1

Geographic location of center of drainage area: Long: 16°58'40" " Lat: 38°12'40" "

Drainage Area: 3.0 – square miles

Storm Frequency (Section 2.3) 100 – year

6-Hour Storm Duration Precipitation (Appendix B): 3.9 – inches

24-Hour Storm Duration Precipitation (Appendix B): 8.3 – inches

Precipitation Zone Number (PZN): PZN = 1.0 ____ 2.0 2.5 3.0 ____ 4.0
(Section 4.1.2.4 and Appendix C)

PZN Ajustment Factor for
5-year to 35-year storm frequency (interpolate): 1.5 ____ 2.5 ____ 2.0 ____ 1.5
(Section 4.1.2.4 and Table 4-6)

PZN Ajustment Factor for
35-year to 150-year storm frequency (interpolate): 2.0 ____ 3.0 3.0 3.0 ____ 2.0
(Section 4.1.2.4 and Table 4-6)

PZN Adjusted Runoff Curve Number (interpolate between nearest whole number PZN conditions): $CN_{1.0}$ or 2.0 69 CN_X 84 $CN_{2.0}$ or 3.0 84
(Sections 4.1.2.4 and 4.2.4, Tables 4-6 and 4-10)

Watershed Length (L) (Section 4.3.1): 4.05 – miles

Length to Centroid (L_c) (Section 4.3.1): 1.78 – miles

Slope (s) (Section 4.3.1): 188 – feet/mile Basin $\bar{n}$ Factor (Section 4.3.5): 0.050

Corps lag (T_L) = 24 $\bar{n}$ $((L \times L_c)/s^{0.5})^m$ (Section 4.3.1.1)
OR
Corps lag (T_L) = 0.8 T_c (Section 4.3.1.2) Lag Time: 0.94 – hours

Time to Peak = 0.862 x Corps lag (Section 4.1.5.5): Time to Peak : 0.81 – hours

SAN DIEGO COUNTY HYDROLOGY MANUAL APPENDIX WB.A
SDUH PEAK DISCHARGE PROGRAM OUTPUR FOR NRCS HYDROLOGIC METHOD EXAMPLE #1

```
*************************************************************************
The special UH program uses the procedures described in Section 4
of the San Diego County Hydrology Manual.  The special UH program
may be used only for determination of peak flow rate, and may not
be used for detention basin design or other routing purposes for
which a hydrograph is required.  To generate a hydrograph,
the calculation method described in Section 4 of the San Diego
County Hydrology Manual may be used, or a computer program that
includes good documentation of the calculations (see Section 1.7 of
the San Diego County Hydrology manual). Note: the RATHYDRO computer
program is not based on the calculation method described in
Section 4 of the San Diego County Hydrology Manual and may not
be used to generate a hydrograph based on the special UH program output.
*************************************************************************

 Project Identification: San Diego County Hydrology Manual Section WB.3.1
 Storm Frequency (years) =  100
 Drainage Area (square miles) =    3.000
 6-Hour Rainfall (inches) =     3.90
 6-Hour Depth-Area Factor =    0.991
 24-Hour Rainfall (inches) =     8.30
 24-Hour Depth-Area Factor =    0.994
 Adjusted Curve Number = 84
 Unit Interval (minutes) =  5
 Watershed Lag Time (hours) =    0.940
 Peak Flow Rate (cfs) =     3265.8
```

APPENDIX WB.B

TABLE FOR CONVOLUTION OF UNIT HYDROGRAPH
FOR
NRCS HYDROLOGIC METHOD EXAMPLE #2

APPENDIX WB.B

NRCS HYDROLOGIC METHOD EXAMPLE #2 TABLE FOR CONVOLUTION OF UNIT HYDROGRAPH
(Page 1 of 8)

	Time (minutes)	15	30	45	60	75	90	105	120	135	150	165	180	
	Effective Rainfall (inches)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Time (minutes)	UH Ordinate (cfs/inch)													Discharge* (cfs)
15	1020	0												0
30	2917	0	0											0
45	6066	0	0	0										0
60	9964	0	0	0	0									0
75	12236	0	0	0	0	0								0
90	12907	0	0	0	0	0	0							0
105	12236	0	0	0	0	0	0	0						0
120	10790	0	0	0	0	0	0	0	0					0
135	8777	0	0	0	0	0	0	0	0	0				0
150	6324	0	0	0	0	0	0	0	0	0	0			0
165	4801	0	0	0	0	0	0	0	0	0	0	0		0
180	3614	0	0	0	0	0	0	0	0	0	0	0	0	0
195	2814	0	0	0	0	0	0	0	0	0	0	0	0	0
210	2168	0	0	0	0	0	0	0	0	0	0	0	0	0
225	1639	0	0	0	0	0	0	0	0	0	0	0	0	2
240	1252	0	0	0	0	0	0	0	0	0	0	0	0	7
255	955	0	0	0	0	0	0	0	0	0	0	0	0	19
270	710	0	0	0	0	0	0	0	0	0	0	0	0	40
285	542	0	0	0	0	0	0	0	0	0	0	0	0	72
300	426	0	0	0	0	0	0	0	0	0	0	0	0	115
315	323	0	0	0	0	0	0	0	0	0	0	0	0	167
330	245	0	0	0	0	0	0	0	0	0	0	0	0	229
345	181	0	0	0	0	0	0	0	0	0	0	0	0	296
360	142	0	0	0	0	0	0	0	0	0	0	0	0	368
375	116	0	0	0	0	0	0	0	0	0	0	0	0	444
390	90	0	0	0	0	0	0	0	0	0	0	0	0	522
405	65	0	0	0	0	0	0	0	0	0	0	0	0	601
420	39	0	0	0	0	0	0	0	0	0	0	0	0	682
435	26	0	0	0	0	0	0	0	0	0	0	0	0	763
450	0	0	0	0	0	0	0	0	0	0	0	0	0	845
465			0	0	0	0	0	0	0	0	0	0	0	928
480				0	0	0	0	0	0	0	0	0	0	1012
495					0	0	0	0	0	0	0	0	0	1096
510						0	0	0	0	0	0	0	0	1180
525							0	0	0	0	0	0	0	1266
540								0	0	0	0	0	0	1352
555									0	0	0	0	0	1439
570										0	0	0	0	1528
585											0	0	0	1617
600												0	0	1709
615													0	1802

*Discharge includes values from columns not shown on this sheet

NRCS HYDROLOGIC METHOD EXAMPLE #2 TABLE FOR CONVOLUTION OF UNIT HYDROGRAPH
(Page 2 of 8)

	Time (minutes)	195	210	225	240	255	270	285	300	315	330	345	360	
	Effective Rainfall (inches)	0.000	0.0003	0.001	0.002	0.003	0.004	0.005	0.005	0.006	0.007	0.008	0.009	
Time (minutes)	UH Ordinate (cfs/inch)													Discharge* (cfs)
195	2814	0												0
210	2168	0	0											0
225	1639	0	1	1										2
240	1252	0	2	3	2									7
255	955	0	3	7	6	3								19
270	710	0	4	12	12	9	4							40
285	542	0	4	14	20	18	11	5						72
300	426	0	4	15	25	29	23	13	6					115
315	323	0	3	14	26	36	38	28	16	6				167
330	245	0	3	13	25	38	46	46	33	18	7			229
345	181	0	2	10	22	36	49	57	54	38	21	8		296
360	142	0	1	7	18	32	46	60	67	63	43	23	9	368
375	116	0	1	6	13	26	41	57	70	77	71	48	25	444
390	90	0	1	4	10	18	33	50	67	81	87	79	53	522
405	65	0	1	3	7	14	24	41	59	77	92	97	87	601
420	39	0	0	3	6	11	18	29	48	68	87	103	107	682
435	26	0	0	2	4	8	14	22	34	55	77	97	113	763
450	0	0	0	1	3	6	11	17	26	40	62	86	107	845
465		0	0	1	3	5	8	13	20	30	45	70	94	928
480		0	0	1	2	4	6	10	15	23	34	50	77	1012
495		0	0	1	1	3	5	8	12	18	26	38	55	1096
510		0	0	0	1	2	4	6	9	14	20	29	42	1180
525		0	0	0	1	2	3	4	7	10	15	22	32	1266
540		0	0	0	1	1	2	3	5	8	12	17	25	1352
555		0	0	0	1	1	2	3	4	6	9	13	19	1439
570		0	0	0	0	1	1	2	3	4	7	10	14	1528
585		0	0	0	0	1	1	1	2	3	5	8	11	1617
600		0	0	0	0	0	1	1	2	3	4	6	8	1709
615		0	0	0	0	0	1	1	1	2	3	4	6	1802
630		0	0	0	0	0	0	1	1	2	2	3	5	1898
645			0	0	0	0	0	1	1	1	2	3	4	1996
660				0	0	0	0	0	1	1	1	2	3	2097
675					0	0	0	0	0	1	1	1	2	2201
690						0	0	0	0	1	1	1	2	2309
705							0	0	0	0	1	1	1	2421
720								0	0	0	0	1	1	2538
735									0	0	0	1	1	2654
750										0	0	0	1	2767
765											0	0	0	2873
780												0	0	2972
795													0	3077

*Discharge includes values from columns not shown on this sheet

APPENDIX WB.B

NRCS HYDROLOGIC METHOD EXAMPLE #2 TABLE FOR CONVOLUTION OF UNIT HYDROGRAPH
(Page 3 of 8)

	Time (minutes)	375	390	405	420	435	450	465	480	495	510	525	540	
	Effective Rainfall (inches)	0.010	0.010	0.011	0.012	0.013	0.014	0.015	0.015	0.016	0.017	0.018	0.019	
Time (minutes)	**UH Ordinate (cfs/inch)**													**Discharge* (cfs)**
375	116	10												444
390	90	28	11											522
405	65	58	30	11										601
420	39	95	63	33	12									682
435	26	117	103	68	35	13								763
450	0	124	127	112	73	38	14							845
465		117	134	137	119	78	40	15						928
480		103	127	145	147	128	83	42	16					1012
495		84	112	137	155	157	136	88	45	17				1096
510		61	91	121	147	166	167	145	93	47	17			1180
525		46	65	98	129	157	176	178	153	99	50	18		1266
540		35	50	71	105	139	167	188	187	162	103	53	19	1352
555		27	37	54	76	113	147	178	198	199	170	109	55	1439
570		21	29	41	58	81	120	157	187	210	209	180	114	1528
585		16	22	32	43	62	86	128	165	199	220	221	188	1617
600		12	17	24	34	46	65	92	134	175	209	233	231	1709
615		9	13	18	26	36	49	70	97	143	184	221	243	1802
630		7	10	14	20	28	38	53	74	103	150	195	231	1898
645		5	7	11	15	21	30	41	55	78	108	158	203	1996
660		4	6	8	11	16	22	32	43	59	82	114	165	2097
675		3	4	6	9	12	17	24	33	46	62	87	119	2201
690		2	3	5	6	9	13	18	25	35	48	65	91	2309
705		2	3	4	5	7	10	14	19	27	37	51	68	2421
720		1	2	3	4	5	7	10	15	20	28	39	53	2538
735		1	1	2	3	4	6	8	11	16	21	30	41	2654
750		1	1	2	2	3	4	6	8	12	16	23	31	2767
765		1	1	1	2	2	3	5	7	9	12	17	24	2873
780		0	1	1	1	2	2	4	5	7	9	13	18	2972
795		0	0	1	1	1	2	3	4	5	7	10	13	3077
810		0	0	0	1	1	2	2	3	4	5	8	10	3194
825			0	0	0	1	1	2	2	3	4	6	8	3328
840				0	0	0	1	1	2	2	3	4	6	3480
855					0	0	1	1	1	2	2	3	5	3671
870						0	0	1	1	1	2	3	3	3918
885							0	0	1	1	2	2	3	4238
900								0	0	1	1	2	2	4648
915									0	0	1	1	2	5133
930										0	0	1	1	5684
945											0	0	1	6361
960												0	0	7205
975													0	8721

*Discharge includes values from columns not shown on this sheet

NRCS HYDROLOGIC METHOD EXAMPLE #2 TABLE FOR CONVOLUTION OF UNIT HYDROGRAPH
(Page 4 of 8)

	Time (minutes)	555	570	585	600	615	630	645	660	675	690	705	720	
	Effective Rainfall (inches)	0.020	0.021	0.022	0.023	0.024	0.025	0.026	0.027	0.029	0.030	0.032	0.033	
Time (minutes)	UH Ordinate (cfs/inch)													Discharge* (cfs)
555		20												1439
570		58	21											1528
585		121	61	22										1617
600		198	126	64	23									1709
615		244	207	133	66	25								1802
630		257	254	218	138	70	25							1898
645		244	268	268	227	146	73	27						1996
660		215	254	283	279	239	151	77	28					2097
675		175	224	268	294	294	249	160	80	30				2201
690		126	182	236	279	310	306	263	166	84	31			2309
705		96	131	192	246	294	322	323	273	176	88	32		2421
720		72	100	138	200	259	306	340	335	288	182	93	34	2538
735		56	75	105	144	211	269	323	353	354	299	193	97	2654
750		43	58	79	109	152	219	284	335	373	368	317	201	2767
765		33	45	62	82	115	158	231	295	354	388	390	330	2873
780		25	34	47	64	87	120	167	240	312	368	411	405	2972
795		19	26	36	49	68	90	127	173	254	324	390	427	3077
810		14	20	27	37	52	70	95	131	183	264	344	405	3194
825		11	15	21	29	39	54	74	99	139	190	280	357	3328
840		8	11	16	22	30	41	57	77	105	144	201	291	3480
855		6	9	12	16	23	31	43	59	81	109	153	209	3671
870		5	7	9	12	17	24	33	45	63	85	115	159	3918
885		4	5	7	10	13	18	25	34	47	65	90	120	4238
900		3	4	5	7	10	14	19	26	36	49	69	93	4648
915		2	3	4	6	8	11	14	19	28	38	52	72	5133
930		2	2	3	4	6	8	11	15	21	29	40	54	5684
945		1	2	3	3	4	6	9	12	16	21	30	41	6361
960		1	1	2	3	3	5	6	9	12	16	23	32	7205
975		1	1	1	2	3	4	5	7	9	13	17	24	8721
990		0	1	1	1	2	3	4	5	7	10	14	18	10849
1005			0	1	1	2	2	3	4	5	7	10	14	13543
1020				0	1	1	2	2	3	4	5	8	11	16389
1035					0	1	1	2	2	3	4	6	8	18108
1050						0	1	1	2	3	3	5	6	**18545**
1065							0	1	1	2	3	4	5	17858
1080								0	1	1	2	3	4	16395
1095									0	1	1	2	3	14479
1110										0	1	1	2	12305
1125											0	1	1	10615
1140												0	1	9241
1155													0	8173

*Discharge includes values from columns not shown on this sheet

NRCS HYDROLOGIC METHOD EXAMPLE #2 TABLE FOR CONVOLUTION OF UNIT HYDROGRAPH
(Page 5 of 8)

Time (minutes)	Time (minutes) / UH Ordinate (cfs/inch)	735	750	765	780	795	810	825	840	855	870	885	900	Discharge* (cfs)
	Effective Rainfall (inches)	0.028	0.034	0.036	0.037	0.040	0.041	0.045	0.047	0.067	0.070	0.076	0.081	
735		29												2654
750		83	34											2767
765		172	98	36										2873
780		283	203	104	38									2972
795		348	334	216	108	40								3077
810		367	410	355	225	116	42							3194
825		348	433	436	369	241	121	46						3328
840		307	410	460	453	395	252	131	48					3480
855		249	362	436	478	485	413	273	138	68				3671
870		180	294	384	453	512	507	448	287	196	71			3918
885		136	212	313	400	485	535	550	472	407	204	78		4238
900		103	161	225	325	428	507	581	580	668	424	222	82	4648
915		80	121	171	234	348	447	550	611	821	697	461	235	5133
930		62	94	129	178	251	364	485	580	866	856	758	490	5684
945		47	73	100	134	190	262	395	511	821	903	930	804	6361
960		36	55	77	104	143	199	285	416	724	856	981	988	7205
975		27	42	58	80	112	150	216	300	589	755	930	1042	8721
990		20	32	45	61	86	117	163	227	424	614	820	988	10849
1005		15	24	34	46	65	90	127	171	322	443	667	871	13543
1020		12	18	25	35	50	68	98	133	242	336	481	708	16389
1035		9	14	19	26	38	52	74	103	189	253	365	510	18108
1050		7	11	15	20	28	40	56	78	145	197	275	388	18545
1065		5	8	11	16	22	29	43	59	110	152	214	292	17858
1080		4	6	9	12	17	22	32	45	84	115	165	227	16395
1095		3	5	6	9	13	18	24	34	64	88	125	175	14479
1110		3	4	5	7	10	13	19	26	48	67	95	132	12305
1125		2	3	4	5	7	10	15	20	36	50	73	101	10615
1140		1	2	3	4	6	7	11	15	29	38	54	77	9241
1155		1	1	2	3	5	6	8	12	22	30	41	57	8173
1170		0	1	1	2	4	5	6	9	16	23	32	44	7304
1185			0	1	1	3	4	5	7	12	17	25	34	6575
1200				0	1	2	3	4	6	10	13	19	26	5982
1215					0	1	2	3	4	8	10	14	20	5489
1230						0	1	2	3	6	8	11	15	5066
1245							0	1	2	4	6	9	11	4719
1260								0	1	3	5	7	9	4432
1275									0	2	3	5	7	4180
1290										0	2	3	5	3965
1305											0	2	3	3776
1320												0	2	3617
1335													0	3480

*Discharge includes values from columns not shown on this sheet

APPENDIX WB.B

NRCS HYDROLOGIC METHOD EXAMPLE #2 TABLE FOR CONVOLUTION OF UNIT HYDROGRAPH
(Page 6 of 8)

Time (minutes)	UH Ordinate (cfs/inch)	915	930	945	960	975	990	1005	1020	1035	1050	1065	1080	Discharge* (cfs)
	Effective Rainfall (inches)	0.093	0.103	0.175	0.166	0.616	0.178	0.097	0.085	0.061	0.054	0.049	0.046	
915		95												5133
930		270	105											5684
945		562	300	178										6361
960		924	624	511	170									7205
975		1134	1025	1062	485	628								8721
990		1196	1259	1744	1009	1798	182							10849
1005		1134	1328	2142	1658	3738	519	99						13543
1020		1000	1259	2259	2036	6140	1080	284	87					16389
1035		814	1110	2142	2148	7540	1774	590	249	62				18108
1050		586	903	1889	2036	7954	2179	970	518	176	55			18545
1065		445	651	1536	1796	7540	2298	1191	850	367	158	50		17858
1080		335	494	1107	1460	6649	2179	1256	1044	603	328	144	47	16395
1095		261	372	840	1052	5409	1921	1191	1101	740	539	300	134	14479
1110		201	289	633	799	3897	1563	1050	1044	781	661	493	279	12305
1125		152	223	492	601	2959	1126	854	921	740	698	605	458	10615
1140		116	169	380	468	2227	855	616	749	653	661	638	563	9241
1155		89	129	287	361	1734	644	467	540	531	583	605	594	8173
1170		66	98	219	273	1336	501	352	410	383	474	534	563	7304
1185		50	73	167	208	1010	386	274	308	291	342	434	496	6575
1200		39	56	124	159	772	292	211	240	219	260	313	404	5982
1215		30	44	95	118	589	223	160	185	170	195	237	291	5489
1230		23	33	75	90	437	170	122	140	131	152	179	221	5066
1245		17	25	56	71	334	126	93	107	99	117	139	166	4719
1260		13	19	43	54	262	97	69	82	76	89	107	129	4432
1275		11	15	32	41	199	76	53	61	58	68	81	100	4180
1290		8	12	25	30	151	57	41	46	43	52	62	75	3965
1305		6	9	20	24	111	44	31	36	33	38	47	58	3776
1320		4	7	16	19	87	32	24	28	26	29	35	44	3617
1335		2	4	11	15	72	25	18	21	20	23	27	33	3480
1350		0	3	7	11	56	21	14	15	15	17	21	25	3354
1365			0	5	6	40	16	11	12	11	13	16	20	3238
1380				0	4	24	11	9	10	9	10	12	15	3131
1395					0	16	7	6	8	7	8	9	11	3040
1410						0	5	4	6	5	6	7	8	2951
1425							0	3	3	4	5	6	7	2880
1440								0	2	2	3	4	5	2817
1455									0	2	2	3	4	2734
1470										0	1	2	3	2612
1485											0	1	2	2420
1500												0	1	2141
1515													0	1815

*Discharge includes values from columns not shown on this sheet

APPENDIX WB.B

NRCS HYDROLOGIC METHOD EXAMPLE #2 TABLE FOR CONVOLUTION OF UNIT HYDROGRAPH
(Page 7 of 8)

	Time (minutes)	1095	1110	1125	1140	1155	1170	1185	1200	1215	1230	1245	1260	
	Effective Rainfall (inches)	0.047	0.044	0.042	0.040	0.038	0.037	0.035	0.034	0.033	0.032	0.031	0.030	
Time (minutes)	**UH Ordinate (cfs/inch)**													**Discharge* (cfs)**
1095		48												14479
1110		137	45											12305
1125		285	129	43										10615
1140		467	268	122	41									9241
1155		574	440	254	116	39								8173
1170		605	540	417	242	111	37							7304
1185		574	570	512	397	231	107	36						6575
1200		506	540	540	487	380	222	103	35					5982
1215		412	476	512	514	466	364	214	99	34				5489
1230		297	387	451	487	492	448	351	206	96	33			5066
1245		225	279	367	430	466	472	431	339	200	93	32		4719
1260		170	212	264	349	411	448	455	416	328	194	91	31	4432
1275		132	160	201	252	334	395	431	439	403	318	188	88	4180
1290		102	124	151	191	241	321	380	416	425	391	310	183	3965
1305		77	96	118	144	183	231	309	367	403	412	380	301	3776
1320		59	72	91	112	138	176	223	299	355	391	401	370	3617
1335		45	55	69	86	107	132	169	215	289	345	380	390	3480
1350		33	42	52	65	83	103	127	163	208	280	335	370	3354
1365		25	31	40	50	62	79	99	123	158	202	273	326	3238
1380		20	24	30	38	48	60	76	96	119	153	196	265	3131
1395		15	19	23	28	36	46	58	74	93	115	149	191	3040
1410		12	14	18	22	27	35	44	56	71	90	112	145	2951
1425		8	11	13	17	21	26	34	43	54	69	87	109	2880
1440		7	8	10	13	16	20	25	32	41	52	67	85	2817
1455		5	6	8	10	12	16	19	24	31	40	51	66	2734
1470		4	5	6	7	9	12	15	18	23	31	39	50	2612
1485		3	4	5	6	7	9	11	14	18	23	30	38	2420
1500		2	3	4	5	5	7	9	11	14	17	22	29	2141
1515		1	2	3	4	4	5	6	8	11	14	17	21	1815
1530		0	1	2	3	3	4	5	6	8	10	13	16	1480
1545			0	1	2	2	3	4	5	6	8	10	13	1166
1560				0	1	1	2	3	4	5	6	8	10	892
1575					0	1	1	2	3	4	5	6	7	670
1590						0	1	1	2	3	4	4	5	509
1605							0	1	1	2	3	4	4	388
1620								0	1	1	2	3	4	296
1635									0	1	1	2	3	225
1650										0	1	1	2	170
1665											0	1	1	128
1680												0	1	97
1695													0	73

*Discharge includes values from columns not shown on this sheet

APPENDIX WB.B

NRCS HYDROLOGIC METHOD EXAMPLE #2 TABLE FOR CONVOLUTION OF UNIT HYDROGRAPH
(Page 8 of 8)

	Time (minutes)	1275	1290	1305	1320	1335	1350	1365	1380	1395	1410	1425	1440	
	Effective Rainfall (inches)	0.029	0.029	0.028	0.028	0.027	0.026	0.026	0.026	0.025	0.025	0.024	0.024	
Time (minutes)	**UH Ordinate (cfs/inch)**													**Discharge* (cfs)**
1275		30												4180
1290		86	29											3965
1305		179	84	29										3776
1320		294	175	82	28									3617
1335		361	287	171	80	28								3480
1350		381	352	280	167	79	27							3354
1365		361	372	344	274	164	77	26						3238
1380		318	352	363	337	269	161	76	26					3131
1395		259	311	344	356	330	264	158	74	26				3040
1410		187	253	304	337	348	324	259	155	73	25			2951
1425		142	182	247	297	330	342	318	254	152	72	25		2880
1440		107	138	178	242	291	324	335	312	250	150	71	24	2817
1455		83	104	135	174	237	286	318	329	307	246	147	70	2734
1470		64	81	102	132	171	232	280	312	324	302	242	145	2612
1485		48	62	79	100	130	167	228	275	307	318	297	238	2420
1500		37	47	61	78	98	127	164	224	271	302	313	292	2141
1515		28	36	46	60	76	96	125	161	220	266	297	308	1815
1530		21	28	35	45	59	74	94	122	159	216	262	292	1480
1545		16	20	27	34	44	57	73	92	120	156	213	258	1166
1560		13	16	20	26	34	43	56	72	91	118	153	210	892
1575		10	12	15	20	26	33	43	55	71	89	117	151	670
1590		7	9	12	15	19	25	33	42	54	69	88	115	509
1605		5	7	9	12	15	19	25	32	41	53	68	86	388
1620		4	5	7	9	11	14	18	24	31	40	53	67	296
1635		3	4	5	7	9	11	14	18	24	31	40	52	225
1650		3	3	4	5	7	9	11	14	18	24	30	39	170
1665		2	3	3	4	5	6	8	11	14	18	23	30	128
1680		1	2	3	3	4	5	6	8	11	13	17	23	97
1695		1	1	2	2	3	4	5	6	8	11	13	17	73
1710		0	1	1	2	2	3	4	5	6	8	10	13	55
1725			0	1	1	2	2	3	4	5	6	8	10	41
1740				0	1	1	2	2	3	4	4	6	8	30
1755					0	1	1	2	2	3	4	4	6	22
1770						0	1	1	2	2	3	3	4	16
1785							0	1	1	2	2	3	3	12
1800								0	1	1	2	2	3	8
1815									0	1	1	2	2	5
1830										0	1	1	2	3
1845											0	1	1	2
1860												0	1	1
1875													0	0

*Discharge includes values from columns not shown on this sheet

APPENDIX WB.C

SDUH PEAK DISCHARGE PROGRAM OUTPUT
AND
HEC-1 INPUT AND OUTPUT
FOR
NRCS HYDROLOGIC METHOD EXAMPLE #1

SAN DIEGO COUNTY HYDROLOGY MANUAL APPENDIX WB.C
SDUH PEAK DISCHARGE PROGRAM OUTPUT FOR NRCS HYDROLOGIC METHOD EXAMPLE #2

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**********************************************************************
The special UH program uses the procedures described in Section 4
of the San Diego County Hydrology Manual.  The special UH program
may be used only for determination of peak flow rate, and may not
be used for detention basin design or other routing purposes for
which a hydrograph is required.  To generate a hydrograph,
the calculation method described in Section 4 of the San Diego
County Hydrology Manual may be used, or a computer program that
includes good documentation of the calculations (see Section 1.7 of
the San Diego County Hydrology manual). Note: the RATHYDRO computer
program is not based on the calculation method described in
Section 4 of the San Diego County Hydrology Manual and may not
be used to generate a hydrograph based on the special UH program output.
**********************************************************************

 Project Identification: San Diego County Hydrology Manual Section WB.3.2
 Storm Frequency (years) =  100
 Drainage Area (square miles) =   40.000
 6-Hour Rainfall (inches) =     3.00
 6-Hour Depth-Area Factor =    0.940
 24-Hour Rainfall (inches) =     5.50
 24-Hour Depth-Area Factor =    0.958
 Adjusted Curve Number = 85
 Unit Interval (minutes) = 15
 Watershed Lag Time (hours) =    1.740
 Peak Flow Rate (cfs) =    18544.1
```

```
*DIAGRAM
ID      HYDROLOGY MANUAL TEST 40 MI2 WATERSHED COMPARE TO SDUH AND HAND CALC
ID      FN: 40MI2.HC1
*FREE
IT 15,01JAN03,1200,300
IO 1,2
KK EXAMPLE
KM NESTED STORM PER COUNTY OF SAN DIEGO HYDROLOGY MANUAL
KM COPYRIGHT 2003 RICK ENGINEERING COMPANY
KM 6HR RAINFALL IS  3  INCHES
KM 24HR RAINFALL IS  5.5  INCHES
KM DAR30 =  .73
KM DAR60 =  .83
KM DAR180 =  .915
KM DAR360 =  .94
KM DAR1440 =  .958
KM BASIN AREA IS  40  SQUARE MILES
IN 15 01JAN90 1200 300
PI .025  .026  .026  .026  .026  .026  .027  .027  .027  .027
PI .028  .028  .028  .028  .029  .029  .029  .030  .030  .030
PI .031  .031  .031  .032  .032  .033  .033  .033  .034  .034
PI .035  .035  .036  .037  .037  .038  .039  .039  .040  .041
PI .042  .043  .044  .045  .047  .048  .049  .050  .043  .050
PI .052  .053  .056  .058  .062  .064  .090  .092  .098  .103
PI .116  .127  .212  .198  .710  .200  .109  .095  .067  .060
PI .055  .051  .052  .048  .046  .044  .042  .040  .038  .037
PI .036  .035  .034  .033  .032  .031  .030  .030  .029  .029
PI .028  .027  .027  .027  .026  .026  0  0  0  0
PI 0  0  0  0  0  0  0  0  0  0
PI 0  0
BA 40.0
LS 0,85
UD 1.375
ZZ
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1***************************************
**************************************
 *                                     *                                                  *
*
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                  *    U.S. ARMY CORPS OF ENGINEERS
*
 *              JUN   1998              *                                                  *    HYDROLOGIC ENGINEERING CENTER
*
 *           VERSION 4.1                 *                                                  *         609 SECOND STREET
*
 *                                     *                                                  *       DAVIS, CALIFORNIA 95616
*
 *  RUN DATE   12MAY03  TIME  16:51:58   *                                                  *           (916) 756-1104
*
 *                                     *                                                  *
*
 ***************************************
**************************************


                                                  X     X  XXXXXXX   XXXXX           X
                                                  X     X  X        X     X         XX
                                                  X     X  X        X                X
                                                  XXXXXXX  XXXX     X        XXXXX   X
                                                  X     X  X        X                X
                                                  X     X  X        X     X          X
                                                  X     X  XXXXXXX   XXXXX          XXX


            THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

            THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
            THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
            NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
            DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
            KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM
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                  ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

                  *DIAGRAM
                  ID        HYDROLOGY MANUAL TEST 40 MI2 WATERSHED COMPARE TO SDUH AND HAND CALC
                  ID        FN: 40MI2.HC1
 *** FREE ***
                  IT      15 01JAN03    1200     300
                  IO       1       2

                  KK EXAMPLE
                  KM   NESTED STORM PER COUNTY OF SAN DIEGO HYDROLOGY MANUAL
                  KM   COPYRIGHT 2003 RICK ENGINEERING COMPANY
                  KM   6HR RAINFALL IS  3  INCHES
                  KM   24HR RAINFALL IS  5.5  INCHES
                  KM   DAR30 =  .73
                  KM   DAR60 =  .83
                  KM   DAR180 =  .915
                  KM   DAR360 =  .94
                  KM   DAR1440 =  .958
                  KM   BASIN AREA IS  40  SQUARE MILES
                  IN      15 01JAN90    1200     300
                  PI    .025    .026    .026    .026    .026    .026    .027    .027    .027    .027
                  PI    .028    .028    .028    .028    .029    .029    .029    .030    .030    .030
                  PI    .031    .031    .031    .032    .032    .033    .033    .033    .034    .034
                  PI    .035    .035    .036    .037    .037    .038    .039    .039    .040    .041
                  PI    .042    .043    .044    .045    .047    .048    .049    .050    .043    .050
                  PI    .052    .053    .056    .058    .062    .064    .090    .092    .098    .103
                  PI    .116    .127    .212    .198    .710    .200    .109    .095    .067    .060
                  PI    .055    .051    .052    .048    .046    .044    .042    .040    .038    .037
                  PI    .036    .035    .034    .033    .032    .031    .030    .030    .029    .029
                  PI    .028    .027    .027    .027    .026    .026       0       0       0       0
                  PI       0       0       0       0       0       0       0       0       0       0
                  PI       0       0
                  BA    40.0
                  LS       0      85
                  UD   1.375
                  ZZ
```

```
1
                 SCHEMATIC DIAGRAM OF STREAM NETWORK
 INPUT
  LINE      (V) ROUTING          (--->) DIVERSION OR PUMP FLOW

   NO.      (.) CONNECTOR        (<---) RETURN OF DIVERTED OR PUMPED FLOW

     5     EXAMPLE

 (***) RUNOFF ALSO COMPUTED AT THIS LOCATION
```

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1***************************************
**************************************
 *                                       *                                                   *
*
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                   *    U.S. ARMY CORPS OF ENGINEERS
*
 *             JUN   1998                *                                                   *    HYDROLOGIC ENGINEERING CENTER
*
 *          VERSION 4.1                  *                                                   *          609 SECOND STREET
*
 *                                       *                                                   *       DAVIS, CALIFORNIA 95616
*
 *  RUN DATE   12MAY03  TIME  16:51:58   *                                                   *           (916) 756-1104
*
 *                                       *                                                   *
*
 ***************************************
**************************************



                                 HYDROLOGY MANUAL TEST 40 MI2 WATERSHED COMPARE TO SDUH AND HAND CALC
                                 FN: 40MI2.HC1

    4 IO          OUTPUT CONTROL VARIABLES
                        IPRNT           1  PRINT CONTROL
                        IPLOT           2  PLOT CONTROL
                        QSCAL          0.  HYDROGRAPH PLOT SCALE

      IT          HYDROGRAPH TIME DATA
                         NMIN          15  MINUTES IN COMPUTATION INTERVAL
                        IDATE      1JAN 3  STARTING DATE
                        ITIME        1200  STARTING TIME
                           NQ         300  NUMBER OF HYDROGRAPH ORDINATES
                       NDDATE      4JAN 3  ENDING DATE
                       NDTIME        1445  ENDING TIME
                       ICENT           19  CENTURY MARK

                  COMPUTATION INTERVAL     .25 HOURS
                       TOTAL TIME BASE   74.75 HOURS

           ENGLISH UNITS
                DRAINAGE AREA         SQUARE MILES
                PRECIPITATION DEPTH   INCHES
                LENGTH, ELEVATION     FEET
                FLOW                  CUBIC FEET PER SECOND
                STORAGE VOLUME        ACRE-FEET
                SURFACE AREA          ACRES
                TEMPERATURE           DEGREES FAHRENHEIT



*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
***
```

```
              **************
              *            *
     5 KK     *   EXAMPLE  *
              *            *
              **************
```

NESTED STORM PER COUNTY OF SAN DIEGO HYDROLOGY MANUAL
COPYRIGHT 2003 RICK ENGINEERING COMPANY
6HR RAINFALL IS 3 INCHES
24HR RAINFALL IS 5.5 INCHES
DAR30 = .73
DAR60 = .83
DAR180 = .915
DAR360 = .94
DAR1440 = .958
BASIN AREA IS 40 SQUARE MILES

16 IN TIME DATA FOR INPUT TIME SERIES
JXMIN 15 TIME INTERVAL IN MINUTES
JXDATE 1JAN90 STARTING DATE
JXTIME 1200 STARTING TIME

SUBBASIN RUNOFF DATA

29 BA SUBBASIN CHARACTERISTICS
TAREA 40.00 SUBBASIN AREA

PRECIPITATION DATA

17 PB STORM 5.27 BASIN TOTAL PRECIPITATION

17 PI INCREMENTAL PRECIPITATION PATTERN

.03	.03	.03	.03	.03	.03	.03	.03	.03	.03
.03	.03	.03	.03	.03	.03	.03	.03	.03	.03
.03	.03	.03	.03	.03	.03	.03	.03	.03	.03
.04	.04	.04	.04	.04	.04	.04	.04	.04	.04
.04	.04	.04	.04	.05	.05	.05	.05	.04	.05
.05	.05	.06	.06	.06	.06	.09	.09	.10	.10
.12	.13	.21	.20	.71	.20	.11	.09	.07	.06
.05	.05	.05	.05	.05	.04	.04	.04	.04	.04
.04	.03	.03	.03	.03	.03	.03	.03	.03	.03
.03	.03	.03	.03	.03	.03				

30 LS SCS LOSS RATE
STRTL .35 INITIAL ABSTRACTION
CRVNBR 85.00 CURVE NUMBER
RTIMP .00 PERCENT IMPERVIOUS AREA

31 UD SCS DIMENSIONLESS UNITGRAPH
TLAG 1.38 LAG

***

UNIT HYDROGRAPH
30 END-OF-PERIOD ORDINATES

988.	2965.	6059.	9884.	12248.	12892.	12248.	10743.	8767.	6360.
4770.	3610.	2826.	2153.	1637.	1251.	945.	709.	548.	421.
322.	245.	185.	142.	116.	90.	64.	43.	21.	0.

****
***

HYDROGRAPH AT STATION EXAMPLE

****
***

DA MON HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q	*	DA MON HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q
1 JAN 1200	1	.00	.00	.00	0.	*	3 JAN 0130	151	.00	.00	.00	0.
1 JAN 1215	2	.03	.03	.00	0.	*	3 JAN 0145	152	.00	.00	.00	0.
1 JAN 1230	3	.03	.03	.00	0.	*	3 JAN 0200	153	.00	.00	.00	0.
1 JAN 1245	4	.03	.03	.00	0.	*	3 JAN 0215	154	.00	.00	.00	0.
1 JAN 1300	5	.03	.03	.00	0.	*	3 JAN 0230	155	.00	.00	.00	0.
1 JAN 1315	6	.03	.03	.00	0.	*	3 JAN 0245	156	.00	.00	.00	0.
1 JAN 1330	7	.03	.03	.00	0.	*	3 JAN 0300	157	.00	.00	.00	0.
1 JAN 1345	8	.03	.03	.00	0.	*	3 JAN 0315	158	.00	.00	.00	0.
1 JAN 1400	9	.03	.03	.00	0.	*	3 JAN 0330	159	.00	.00	.00	0.
1 JAN 1415	10	.03	.03	.00	0.	*	3 JAN 0345	160	.00	.00	.00	0.
1 JAN 1430	11	.03	.03	.00	0.	*	3 JAN 0400	161	.00	.00	.00	0.
1 JAN 1445	12	.03	.03	.00	0.	*	3 JAN 0415	162	.00	.00	.00	0.
1 JAN 1500	13	.03	.03	.00	0.	*	3 JAN 0430	163	.00	.00	.00	0.
1 JAN 1515	14	.03	.03	.00	0.	*	3 JAN 0445	164	.00	.00	.00	0.
1 JAN 1530	15	.03	.03	.00	0.	*	3 JAN 0500	165	.00	.00	.00	0.
1 JAN 1545	16	.03	.03	.00	2.	*	3 JAN 0515	166	.00	.00	.00	0.
1 JAN 1600	17	.03	.03	.00	7.	*	3 JAN 0530	167	.00	.00	.00	0.
1 JAN 1615	18	.03	.03	.00	19.	*	3 JAN 0545	168	.00	.00	.00	0.
1 JAN 1630	19	.03	.03	.00	39.	*	3 JAN 0600	169	.00	.00	.00	0.
1 JAN 1645	20	.03	.03	.00	71.	*	3 JAN 0615	170	.00	.00	.00	0.

1 JAN 1700	21	.03	.02	.01	114.	*	3 JAN 0630	171	.00	.00	.00	0.
1 JAN 1715	22	.03	.02	.01	167.	*	3 JAN 0645	172	.00	.00	.00	0.
1 JAN 1730	23	.03	.02	.01	228.	*	3 JAN 0700	173	.00	.00	.00	0.
1 JAN 1745	24	.03	.02	.01	295.	*	3 JAN 0715	174	.00	.00	.00	0.
1 JAN 1800	25	.03	.02	.01	368.	*	3 JAN 0730	175	.00	.00	.00	0.
1 JAN 1815	26	.03	.02	.01	443.	*	3 JAN 0745	176	.00	.00	.00	0.
1 JAN 1830	27	.03	.02	.01	520.	*	3 JAN 0800	177	.00	.00	.00	0.
1 JAN 1845	28	.03	.02	.01	600.	*	3 JAN 0815	178	.00	.00	.00	0.
1 JAN 1900	29	.03	.02	.01	680.	*	3 JAN 0830	179	.00	.00	.00	0.
1 JAN 1915	30	.03	.02	.01	762.	*	3 JAN 0845	180	.00	.00	.00	0.
1 JAN 1930	31	.03	.02	.01	844.	*	3 JAN 0900	181	.00	.00	.00	0.
1 JAN 1945	32	.04	.02	.01	926.	*	3 JAN 0915	182	.00	.00	.00	0.
1 JAN 2000	33	.04	.02	.02	1008.	*	3 JAN 0930	183	.00	.00	.00	0.
1 JAN 2015	34	.04	.02	.02	1090.	*	3 JAN 0945	184	.00	.00	.00	0.
1 JAN 2030	35	.04	.02	.02	1173.	*	3 JAN 1000	185	.00	.00	.00	0.
1 JAN 2045	36	.04	.02	.02	1257.	*	3 JAN 1015	186	.00	.00	.00	0.
1 JAN 2100	37	.04	.02	.02	1343.	*	3 JAN 1030	187	.00	.00	.00	0.
1 JAN 2115	38	.04	.02	.02	1430.	*	3 JAN 1045	188	.00	.00	.00	0.
1 JAN 2130	39	.04	.02	.02	1518.	*	3 JAN 1100	189	.00	.00	.00	0.
1 JAN 2145	40	.04	.02	.02	1608.	*	3 JAN 1115	190	.00	.00	.00	0.
1 JAN 2200	41	.04	.02	.02	1699.	*	3 JAN 1130	191	.00	.00	.00	0.
1 JAN 2215	42	.04	.02	.02	1791.	*	3 JAN 1145	192	.00	.00	.00	0.
1 JAN 2230	43	.04	.02	.03	1886.	*	3 JAN 1200	193	.00	.00	.00	0.
1 JAN 2245	44	.04	.02	.03	1983.	*	3 JAN 1215	194	.00	.00	.00	0.
1 JAN 2300	45	.04	.02	.03	2083.	*	3 JAN 1230	195	.00	.00	.00	0.
1 JAN 2315	46	.05	.02	.03	2187.	*	3 JAN 1245	196	.00	.00	.00	0.
1 JAN 2330	47	.05	.02	.03	2296.	*	3 JAN 1300	197	.00	.00	.00	0.
1 JAN 2345	48	.05	.02	.03	2410.	*	3 JAN 1315	198	.00	.00	.00	0.
2 JAN 0000	49	.05	.02	.03	2529.	*	3 JAN 1330	199	.00	.00	.00	0.
2 JAN 0015	50	.04	.01	.03	2647.	*	3 JAN 1345	200	.00	.00	.00	0.
2 JAN 0030	51	.05	.02	.03	2760.	*	3 JAN 1400	201	.00	.00	.00	0.
2 JAN 0045	52	.05	.02	.04	2867.	*	3 JAN 1415	202	.00	.00	.00	0.
2 JAN 0100	53	.05	.02	.04	2967.	*	3 JAN 1430	203	.00	.00	.00	0.
2 JAN 0115	54	.06	.02	.04	3074.	*	3 JAN 1445	204	.00	.00	.00	0.
2 JAN 0130	55	.06	.02	.04	3191.	*	3 JAN 1500	205	.00	.00	.00	0.
2 JAN 0145	56	.06	.02	.05	3325.	*	3 JAN 1515	206	.00	.00	.00	0.
2 JAN 0200	57	.06	.02	.05	3477.	*	3 JAN 1530	207	.00	.00	.00	0.
2 JAN 0215	58	.09	.02	.07	3667.	*	3 JAN 1545	208	.00	.00	.00	0.
2 JAN 0230	59	.09	.02	.07	3915.	*	3 JAN 1600	209	.00	.00	.00	0.
2 JAN 0245	60	.10	.02	.08	4234.	*	3 JAN 1615	210	.00	.00	.00	0.
2 JAN 0300	61	.10	.02	.08	4642.	*	3 JAN 1630	211	.00	.00	.00	0.
2 JAN 0315	62	.12	.02	.09	5126.	*	3 JAN 1645	212	.00	.00	.00	0.
2 JAN 0330	63	.13	.02	.10	5674.	*	3 JAN 1700	213	.00	.00	.00	0.
2 JAN 0345	64	.21	.04	.17	6347.	*	3 JAN 1715	214	.00	.00	.00	0.
2 JAN 0400	65	.20	.03	.17	7190.	*	3 JAN 1730	215	.00	.00	.00	0.
2 JAN 0415	66	.71	.09	.62	8687.	*	3 JAN 1745	216	.00	.00	.00	0.
2 JAN 0430	67	.20	.02	.18	10841.	*	3 JAN 1800	217	.00	.00	.00	0.
2 JAN 0445	68	.11	.01	.10	13512.	*	3 JAN 1815	218	.00	.00	.00	0.
2 JAN 0500	69	.09	.01	.09	16320.	*	3 JAN 1830	219	.00	.00	.00	0.
2 JAN 0515	70	.07	.01	.06	18082.	*	3 JAN 1845	220	.00	.00	.00	0.
2 JAN 0530	71	.06	.01	.05	18512.	*	3 JAN 1900	221	.00	.00	.00	0.
2 JAN 0545	72	.05	.01	.05	17841.	*	3 JAN 1915	222	.00	.00	.00	0.
2 JAN 0600	73	.05	.00	.05	16362.	*	3 JAN 1930	223	.00	.00	.00	0.
2 JAN 0615	74	.05	.00	.05	14463.	*	3 JAN 1945	224	.00	.00	.00	0.
2 JAN 0630	75	.05	.00	.04	12319.	*	3 JAN 2000	225	.00	.00	.00	0.
2 JAN 0645	76	.05	.00	.04	10605.	*	3 JAN 2015	226	.00	.00	.00	0.
2 JAN 0700	77	.04	.00	.04	9242.	*	3 JAN 2030	227	.00	.00	.00	0.
2 JAN 0715	78	.04	.00	.04	8185.	*	3 JAN 2045	228	.00	.00	.00	0.
2 JAN 0730	79	.04	.00	.04	7304.	*	3 JAN 2100	229	.00	.00	.00	0.
2 JAN 0745	80	.04	.00	.03	6581.	*	3 JAN 2115	230	.00	.00	.00	0.
2 JAN 0800	81	.04	.00	.03	5989.	*	3 JAN 2130	231	.00	.00	.00	0.
2 JAN 0815	82	.04	.00	.03	5492.	*	3 JAN 2145	232	.00	.00	.00	0.
2 JAN 0830	83	.03	.00	.03	5071.	*	3 JAN 2200	233	.00	.00	.00	0.
2 JAN 0845	84	.03	.00	.03	4727.	*	3 JAN 2215	234	.00	.00	.00	0.
2 JAN 0900	85	.03	.00	.03	4435.	*	3 JAN 2230	235	.00	.00	.00	0.
2 JAN 0915	86	.03	.00	.03	4186.	*	3 JAN 2245	236	.00	.00	.00	0.
2 JAN 0930	87	.03	.00	.03	3971.	*	3 JAN 2300	237	.00	.00	.00	0.
2 JAN 0945	88	.03	.00	.03	3785.	*	3 JAN 2315	238	.00	.00	.00	0.
2 JAN 1000	89	.03	.00	.03	3623.	*	3 JAN 2330	239	.00	.00	.00	0.
2 JAN 1015	90	.03	.00	.03	3483.	*	3 JAN 2345	240	.00	.00	.00	0.
2 JAN 1030	91	.03	.00	.03	3355.	*	4 JAN 0000	241	.00	.00	.00	0.
2 JAN 1045	92	.03	.00	.03	3237.	*	4 JAN 0015	242	.00	.00	.00	0.
2 JAN 1100	93	.03	.00	.03	3131.	*	4 JAN 0030	243	.00	.00	.00	0.
2 JAN 1115	94	.03	.00	.03	3035.	*	4 JAN 0045	244	.00	.00	.00	0.
2 JAN 1130	95	.03	.00	.03	2947.	*	4 JAN 0100	245	.00	.00	.00	0.
2 JAN 1145	96	.03	.00	.02	2876.	*	4 JAN 0115	246	.00	.00	.00	0.
2 JAN 1200	97	.03	.00	.02	2813.	*	4 JAN 0130	247	.00	.00	.00	0.
2 JAN 1215	98	.00	.00	.00	2733.	*	4 JAN 0145	248	.00	.00	.00	0.
2 JAN 1230	99	.00	.00	.00	2611.	*	4 JAN 0200	249	.00	.00	.00	0.
2 JAN 1245	100	.00	.00	.00	2420.	*	4 JAN 0215	250	.00	.00	.00	0.
2 JAN 1300	101	.00	.00	.00	2144.	*	4 JAN 0230	251	.00	.00	.00	0.
2 JAN 1315	102	.00	.00	.00	1818.	*	4 JAN 0245	252	.00	.00	.00	0.
2 JAN 1330	103	.00	.00	.00	1483.	*	4 JAN 0300	253	.00	.00	.00	0.
2 JAN 1345	104	.00	.00	.00	1168.	*	4 JAN 0315	254	.00	.00	.00	0.
2 JAN 1400	105	.00	.00	.00	894.	*	4 JAN 0330	255	.00	.00	.00	0.
2 JAN 1415	106	.00	.00	.00	672.	*	4 JAN 0345	256	.00	.00	.00	0.
2 JAN 1430	107	.00	.00	.00	510.	*	4 JAN 0400	257	.00	.00	.00	0.
2 JAN 1445	108	.00	.00	.00	389.	*	4 JAN 0415	258	.00	.00	.00	0.
2 JAN 1500	109	.00	.00	.00	297.	*	4 JAN 0430	259	.00	.00	.00	0.

2	JAN	1515	110	.00	.00	.00	225.	*	4	JAN	0445	260	.00	.00	.00	0.
2	JAN	1530	111	.00	.00	.00	170.	*	4	JAN	0500	261	.00	.00	.00	0.
2	JAN	1545	112	.00	.00	.00	129.	*	4	JAN	0515	262	.00	.00	.00	0.
2	JAN	1600	113	.00	.00	.00	97.	*	4	JAN	0530	263	.00	.00	.00	0.
2	JAN	1615	114	.00	.00	.00	73.	*	4	JAN	0545	264	.00	.00	.00	0.
2	JAN	1630	115	.00	.00	.00	55.	*	4	JAN	0600	265	.00	.00	.00	0.
2	JAN	1645	116	.00	.00	.00	41.	*	4	JAN	0615	266	.00	.00	.00	0.
2	JAN	1700	117	.00	.00	.00	31.	*	4	JAN	0630	267	.00	.00	.00	0.
2	JAN	1715	118	.00	.00	.00	23.	*	4	JAN	0645	268	.00	.00	.00	0.
2	JAN	1730	119	.00	.00	.00	16.	*	4	JAN	0700	269	.00	.00	.00	0.
2	JAN	1745	120	.00	.00	.00	12.	*	4	JAN	0715	270	.00	.00	.00	0.
2	JAN	1800	121	.00	.00	.00	8.	*	4	JAN	0730	271	.00	.00	.00	0.
2	JAN	1815	122	.00	.00	.00	5.	*	4	JAN	0745	272	.00	.00	.00	0.
2	JAN	1830	123	.00	.00	.00	3.	*	4	JAN	0800	273	.00	.00	.00	0.
2	JAN	1845	124	.00	.00	.00	2.	*	4	JAN	0815	274	.00	.00	.00	0.
2	JAN	1900	125	.00	.00	.00	1.	*	4	JAN	0830	275	.00	.00	.00	0.
2	JAN	1915	126	.00	.00	.00	0.	*	4	JAN	0845	276	.00	.00	.00	0.
2	JAN	1930	127	.00	.00	.00	0.	*	4	JAN	0900	277	.00	.00	.00	0.
2	JAN	1945	128	.00	.00	.00	0.	*	4	JAN	0915	278	.00	.00	.00	0.
2	JAN	2000	129	.00	.00	.00	0.	*	4	JAN	0930	279	.00	.00	.00	0.
2	JAN	2015	130	.00	.00	.00	0.	*	4	JAN	0945	280	.00	.00	.00	0.
2	JAN	2030	131	.00	.00	.00	0.	*	4	JAN	1000	281	.00	.00	.00	0.
2	JAN	2045	132	.00	.00	.00	0.	*	4	JAN	1015	282	.00	.00	.00	0.
2	JAN	2100	133	.00	.00	.00	0.	*	4	JAN	1030	283	.00	.00	.00	0.
2	JAN	2115	134	.00	.00	.00	0.	*	4	JAN	1045	284	.00	.00	.00	0.
2	JAN	2130	135	.00	.00	.00	0.	*	4	JAN	1100	285	.00	.00	.00	0.
2	JAN	2145	136	.00	.00	.00	0.	*	4	JAN	1115	286	.00	.00	.00	0.
2	JAN	2200	137	.00	.00	.00	0.	*	4	JAN	1130	287	.00	.00	.00	0.
2	JAN	2215	138	.00	.00	.00	0.	*	4	JAN	1145	288	.00	.00	.00	0.
2	JAN	2230	139	.00	.00	.00	0.	*	4	JAN	1200	289	.00	.00	.00	0.
2	JAN	2245	140	.00	.00	.00	0.	*	4	JAN	1215	290	.00	.00	.00	0.
2	JAN	2300	141	.00	.00	.00	0.	*	4	JAN	1230	291	.00	.00	.00	0.
2	JAN	2315	142	.00	.00	.00	0.	*	4	JAN	1245	292	.00	.00	.00	0.
2	JAN	2330	143	.00	.00	.00	0.	*	4	JAN	1300	293	.00	.00	.00	0.
2	JAN	2345	144	.00	.00	.00	0.	*	4	JAN	1315	294	.00	.00	.00	0.
3	JAN	0000	145	.00	.00	.00	0.	*	4	JAN	1330	295	.00	.00	.00	0.
3	JAN	0015	146	.00	.00	.00	0.	*	4	JAN	1345	296	.00	.00	.00	0.
3	JAN	0030	147	.00	.00	.00	0.	*	4	JAN	1400	297	.00	.00	.00	0.
3	JAN	0045	148	.00	.00	.00	0.	*	4	JAN	1415	298	.00	.00	.00	0.
3	JAN	0100	149	.00	.00	.00	0.	*	4	JAN	1430	299	.00	.00	.00	0.
3	JAN	0115	150	.00	.00	.00	0.	*	4	JAN	1445	300	.00	.00	.00	0.
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     TOTAL RAINFALL =    5.27, TOTAL LOSS =    1.65, TOTAL EXCESS =    3.62

  PEAK FLOW     TIME                          MAXIMUM AVERAGE FLOW
                                   6-HR        24-HR       72-HR      74.75-HR
+   (CFS)       (HR)
                            (CFS)
+   18512.     17.50               9959.       3889.       1297.        1249.
                         (INCHES)  2.315       3.615       3.617        3.617
                          (AC-FT)  4938.       7713.       7717.        7717.

                          CUMULATIVE AREA =   40.00 SQ MI
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                                  (O) OUTFLOW
          0.      4000.      8000.    12000.    16000.    20000.         0.         0.         0.         0.         0.         0.
0.
                                                                                                                (L) PRECIP,   (X) EXCESS
          .0         .0         .0         .0         .0         .0         .0         .0         .8         .6         .4         .2
.0
 DAHRMN PER
  11200   1O---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.------
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  11215   2O         .         .         .         .         .         .         .         .         .         .         .
L.
  11230   3O         .         .         .         .         .         .         .         .         .         .         .
L.
  11245   4O         .         .         .         .         .         .         .         .         .         .         .
L.
  11300   5O         .         .         .         .         .         .         .         .         .         .         .
L.
  11315   6O         .         .         .         .         .         .         .         .         .         .         .
L.
  11330   7O         .         .         .         .         .         .         .         .         .         .         .
L.
  11345   8O         .         .         .         .         .         .         .         .         .         .         .
L.
  11400   9O         .         .         .         .         .         .         .         .         .         .         .
L.
  11415  10O         .         .         .         .         .         .         .         .         .         .         .
L.
  11430  11O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
.L.
  11445  12O         .         .         .         .         .         .         .         .         .         .         .
L.
  11500  13O         .         .         .         .         .         .         .         .         .         .         .
L.
  11515  14O         .         .         .         .         .         .         .         .         .         .         .
L.
  11530  15O         .         .         .         .         .         .         .         .         .         .         .
L.
  11545  16O         .         .         .         .         .         .         .         .         .         .         .
L.
  11600  17O         .         .         .         .         .         .         .         .         .         .         .
L.
  11615  18O         .         .         .         .         .         .         .         .         .         .         .
L.
  11630  19O         .         .         .         .         .         .         .         .         .         .         .
L.
  11645  20O         .         .         .         .         .         .         .         .         .         .         .
L.
  11700  21O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
.L.
  11715  22O         .         .         .         .         .         .         .         .         .         .         .
LL.
  11730  23.O        .         .         .         .         .         .         .         .         .         .         .
LL.
  11745  24.O        .         .         .         .         .         .         .         .         .         .         .
LL.
  11800  25.O        .         .         .         .         .         .         .         .         .         .         .
LL.
  11815  26.O        .         .         .         .         .         .         .         .         .         .         .
LL.
  11830  27.O        .         .         .         .         .         .         .         .         .         .         .
LX.
  11845  28.O        .         .         .         .         .         .         .         .         .         .         .
LX.
  11900  29. O       .         .         .         .         .         .         .         .         .         .         .
LX.
  11915  30. O       .         .         .         .         .         .         .         .         .         .         .
LX.
  11930  31. O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
LX.
  11945  32. O       .         .         .         .         .         .         .         .         .         .         .
LX.
  12000  33.  O      .         .         .         .         .         .         .         .         .         .         .
LX.
  12015  34.  O      .         .         .         .         .         .         .         .         .         .         .
LX.
  12030  35.  O      .         .         .         .         .         .         .         .         .         .         .
LX.
  12045  36.  O      .         .         .         .         .         .         .         .         .         .         .
LX.
  12100  37.  O      .         .         .         .         .         .         .         .         .         .         .
LX.
  12115  38.   O     .         .         .         .         .         .         .         .         .         .         .
LX.
  12130  39.   O     .         .         .         .         .         .         .         .         .         .         .
LX.
  12145  40.   O     .         .         .         .         .         .         .         .         .         .         .
LX.
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  12200  41. . O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
LX.
  12215  42.   O     .         .         .         .         .         .         .         .         .         .         .
LX.
  12230  43.    O    .         .         .         .         .         .         .         .         .         .         .
LX.
  12245  44.    O    .         .         .         .         .         .         .         .         .         .         .
LX.
  12300  45.    O    .         .         .         .         .         .         .         .         .         .         .
LX.
  12315  46.    O    .         .         .         .         .         .         .         .         .         .         .
LX.
  12330  47.     O   .         .         .         .         .         .         .         .         .         .         .
XX.
  12345  48.     O   .         .         .         .         .         .         .         .         .         .         .
XX.
  20000  49.     O   .         .         .         .         .         .         .         .         .         .         .
XX.
  20015  50.      O  .         .         .         .         .         .         .         .         .         .         .
LX.
  20030  51. . . .O. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
XX.
  20045  52.      O  .         .         .         .         .         .         .         .         .         .         .
LXX.
  20100  53.      O  .         .         .         .         .         .         .         .         .         .         .
LXX.
  20115  54.       O .         .         .         .         .         .         .         .         .         .         .
LXX.
  20130  55.       O .         .         .         .         .         .         .         .         .         .         .
LXX.
  20145  56.       O .         .         .         .         .         .         .         .         .         .         .
LXX.
  20200  57.        O.         .         .         .         .         .         .         .         .         .         .
LXX.
  20215  58.        O.         .         .         .         .         .         .         .         .         .         .
LXXX.
  20230  59.         O         .         .         .         .         .         .         .         .         .         .
LLXXX.
  20245  60.         .O        .         .         .         .         .         .         .         .         .         .
LXXXX.
  20300  61. . . . . . O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
.LXXXX.
  20315  62.         .  O      .         .         .         .         .         .         .         .         .         .
LXXXXX.
  20330  63.         .   O     .         .         .         .         .         .         .         .         .         .
LXXXXX.
  20345  64.         .     O   .         .         .         .         .         .         .         .         .
LLXXXXXXXXX.
  20400  65.         .       O .         .         .         .         .         .         .         .         .
LLXXXXXXXX.
  20415  66.         .         . O       .         .         .         .         .         .
LLLLXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX.
  20430  67.         .         .      O  .         .         .         .         .         .         .         .
LXXXXXXXXX.
  20445  68.         .         .         .   O     .         .         .         .         .         .         .
XXXXX.
  20500  69.         .         .         .         .O        .         .         .         .         .         .
LXXXX.
  20515  70.         .         .         .         .    O    .         .         .         .         .         .
XXX.
  20530  71. . . . . . . . . . . . . . . . . . . . . . . O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
.XXX.
  20545  72.         .         .         .         .    O    .         .         .         .         .         .
LXX.
  20600  73.         .         .         .         .O        .         .         .         .         .         .
LXX.
  20615  74.         .         .         .     O   .         .         .         .         .         .         .
LXX.
  20630  75.         .         .         .O        .         .         .         .         .         .         .
XX.
  20645  76.         .         .      O  .         .         .         .         .         .         .         .
XX.
  20700  77.         .         .  O      .         .         .         .         .         .         .         .
XX.
  20715  78.         .         O         .         .         .         .         .         .         .         .
XX.
  20730  79.         .       O .         .         .         .         .         .         .         .         .
XX.
  20745  80.         .     O   .         .         .         .         .         .         .         .         .
XX.
  20800  81. . . . . . . .O. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
XX.
  20815  82.         .   O     .         .         .         .         .         .         .         .         .         .
XX.
  20830  83.         .  O      .         .         .         .         .         .         .         .         .         .
XX.
  20845  84.         . O       .         .         .         .         .         .         .         .         .         .
XX.
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  20900  85.         .O        .         .         .         .         .         .         .         .         .         .
XX.
  20915  86.         O         .         .         .         .         .         .         .         .         .         .
LX.
  20930  87.         O         .         .         .         .         .         .         .         .         .         .
LX.
  20945  88.        O.         .         .         .         .         .         .         .         .         .         .
LX.
  21000  89.        O.         .         .         .         .         .         .         .         .         .         .
LX.
  21015  90.        O.         .         .         .         .         .         .         .         .         .         .
X.
  21030  91. . . . O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
.X.
  21045  92.       O .         .         .         .         .         .         .         .         .         .         .
X.
  21100  93.       O .         .         .         .         .         .         .         .         .         .         .
X.
  21115  94.       O .         .         .         .         .         .         .         .         .         .         .
X.
  21130  95.      O  .         .         .         .         .         .         .         .         .         .         .
X.
  21145  96.      O  .         .         .         .         .         .         .         .         .         .         .
X.
  21200  97.      O  .         .         .         .         .         .         .         .         .         .         .
X.
  21215  98.      O  .         .         .         .         .         .         .         .         .         .         .
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  21230  99.      O  .         .         .         .         .         .         .         .         .         .         .
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  21245 100.     O   .         .         .         .         .         .         .         .         .         .         .
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  21300 101. . .O. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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  21315 102.    O    .         .         .         .         .         .         .         .         .         .         .
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  21330 103.   O     .         .         .         .         .         .         .         .         .         .         .
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  21345 104.  O      .         .         .         .         .         .         .         .         .         .         .
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  21400 105. O       .         .         .         .         .         .         .         .         .         .         .
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  21415 106. O       .         .         .         .         .         .         .         .         .         .         .
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  21430 107.O        .         .         .         .         .         .         .         .         .         .         .
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  21445 108.O        .         .         .         .         .         .         .         .         .         .         .
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  21500 109.O        .         .         .         .         .         .         .         .         .         .         .
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  21515 110.O        .         .         .         .         .         .         .         .         .         .         .
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  21530 111O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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  21545 112O         .         .         .         .         .         .         .         .         .         .         .
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  21600 113O         .         .         .         .         .         .         .         .         .         .         .
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  21615 114O         .         .         .         .         .         .         .         .         .         .         .
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  21630 115O         .         .         .         .         .         .         .         .         .         .         .
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  21645 116O         .         .         .         .         .         .         .         .         .         .         .
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  21700 117O         .         .         .         .         .         .         .         .         .         .         .
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  21715 118O         .         .         .         .         .         .         .         .         .         .         .
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  21730 119O         .         .         .         .         .         .         .         .         .         .         .
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  21745 120O         .         .         .         .         .         .         .         .         .         .         .
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  21800 121O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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  21815 122O         .         .         .         .         .         .         .         .         .         .         .
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  21830 123O         .         .         .         .         .         .         .         .         .         .         .
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  21845 124O         .         .         .         .         .         .         .         .         .         .         .
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  21900 125O         .         .         .         .         .         .         .         .         .         .         .
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  21915 126O         .         .         .         .         .         .         .         .         .         .         .
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  21930 127O         .         .         .         .         .         .         .         .         .         .         .
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  21945 128O         .         .         .         .         .         .         .         .         .         .         .
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22000 1290       .       .       .       .       .       .       .       .       .       .       .
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22015 1300       .       .       .       .       .       .       .       .       .       .       .
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22030 1310 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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22045 1320       .       .       .       .       .       .       .       .       .       .       .
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22100 1330       .       .       .       .       .       .       .       .       .       .       .
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22115 1340       .       .       .       .       .       .       .       .       .       .       .
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22130 1350       .       .       .       .       .       .       .       .       .       .       .
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22145 1360       .       .       .       .       .       .       .       .       .       .       .
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22200 1370       .       .       .       .       .       .       .       .       .       .       .
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22215 1380       .       .       .       .       .       .       .       .       .       .       .
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22230 1390       .       .       .       .       .       .       .       .       .       .       .
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22245 1400       .       .       .       .       .       .       .       .       .       .       .
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22300 1410 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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22315 1420       .       .       .       .       .       .       .       .       .       .       .
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22330 1430       .       .       .       .       .       .       .       .       .       .       .
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22345 1440       .       .       .       .       .       .       .       .       .       .       .
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30000 1450       .       .       .       .       .       .       .       .       .       .       .
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30015 1460       .       .       .       .       .       .       .       .       .       .       .
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30030 1470       .       .       .       .       .       .       .       .       .       .       .
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30045 1480       .       .       .       .       .       .       .       .       .       .       .
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30100 1490       .       .       .       .       .       .       .       .       .       .       .
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30115 1500       .       .       .       .       .       .       .       .       .       .       .
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30130 1510 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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30145 1520       .       .       .       .       .       .       .       .       .       .       .
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30200 1530       .       .       .       .       .       .       .       .       .       .       .
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30215 1540       .       .       .       .       .       .       .       .       .       .       .
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30230 1550       .       .       .       .       .       .       .       .       .       .       .
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30245 1560       .       .       .       .       .       .       .       .       .       .       .
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30300 1570       .       .       .       .       .       .       .       .       .       .       .
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30315 1580       .       .       .       .       .       .       .       .       .       .       .
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30330 1590       .       .       .       .       .       .       .       .       .       .       .
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30345 1600       .       .       .       .       .       .       .       .       .       .       .
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30400 1610 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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30415 1620       .       .       .       .       .       .       .       .       .       .       .
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30430 1630       .       .       .       .       .       .       .       .       .       .       .
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30445 1640       .       .       .       .       .       .       .       .       .       .       .
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30500 1650       .       .       .       .       .       .       .       .       .       .       .
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30515 1660       .       .       .       .       .       .       .       .       .       .       .
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30530 1670       .       .       .       .       .       .       .       .       .       .       .
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30545 1680       .       .       .       .       .       .       .       .       .       .       .
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30600 1690       .       .       .       .       .       .       .       .       .       .       .
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30615 1700       .       .       .       .       .       .       .       .       .       .       .
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30630 1710 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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30645 1720       .       .       .       .       .       .       .       .       .       .       .
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30700 1730 . . . .
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30715 1740 . . . .
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30730 1750 . . . .
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30745 1760 . . . .
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30800 1770 . . . .
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30815 1780 . . . .
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30830 1790 . . . .
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30845 1800 . . . .
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30900 1810 . . . .
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30915 1820 . . . .
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30930 1830 . . . .
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30945 1840 . . . .
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31000 1850 . . . .
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31015 1860 . . . .
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31030 1870 . . . .
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31045 1880 . . . .
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31100 1890 . . . .
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31115 1900 . . . .
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31130 1910 . . . .
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31145 1920 . . . .
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31200 1930 . . . .
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31215 1940 . . . .
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31230 1950 . . . .
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31245 1960 . . . .
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31300 1970 . . . .
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31315 1980 . . . .
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31330 1990 . . . .
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31345 2000 . . . .
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31400 2010 . . . .
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31415 2020 . . . .
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31430 2030 . . . .
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31445 2040 . . . .
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31500 2050 . . . .
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31515 2060 . . . .
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31530 2070 . . . .
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31545 2080 . . . .
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31600 2090 . . . .
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31615 2100 . . . .
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31630 2110 . . . .
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31645 2120 . . . .
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31700 2130 . . . .
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31715 2140 . . . .
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31730 2150 . . . .
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31745 2160 . . . .
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31800 2170 . . . . . . . . . . . .
31815 2180 . . . . . . . . . . . .
31830 2190 . . . . . . . . . . . .
31845 2200 . . . . . . . . . . . .
31900 2210 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
31915 2220 . . . . . . . . . . . .
31930 2230 . . . . . . . . . . . .
31945 2240 . . . . . . . . . . . .
32000 2250 . . . . . . . . . . . .
32015 2260 . . . . . . . . . . . .
32030 2270 . . . . . . . . . . . .
32045 2280 . . . . . . . . . . . .
32100 2290 . . . . . . . . . . . .
32115 2300 . . . . . . . . . . . .
32130 2310 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
32145 2320 . . . . . . . . . . . .
32200 2330 . . . . . . . . . . . .
32215 2340 . . . . . . . . . . . .
32230 2350 . . . . . . . . . . . .
32245 2360 . . . . . . . . . . . .
32300 2370 . . . . . . . . . . . .
32315 2380 . . . . . . . . . . . .
32330 2390 . . . . . . . . . . . .
32345 2400 . . . . . . . . . . . .
40000 2410 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
40015 2420 . . . . . . . . . . . .
40030 2430 . . . . . . . . . . . .
40045 2440 . . . . . . . . . . . .
40100 2450 . . . . . . . . . . . .
40115 2460 . . . . . . . . . . . .
40130 2470 . . . . . . . . . . . .
40145 2480 . . . . . . . . . . . .
40200 2490 . . . . . . . . . . . .
40215 2500 . . . . . . . . . . . .
40230 2510 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
40245 2520 . . . . . . . . . . . .
40300 2530 . . . . . . . . . . . .
40315 2540 . . . . . . . . . . . .
40330 2550 . . . . . . . . . . . .
40345 2560 . . . . . . . . . . . .
40400 2570 . . . . . . . . . . . .
40415 2580 . . . . . . . . . . . .
40430 2590 . . . . . . . . . . . .
40445 2600 . . . . . . . . . . . .
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  40500 2610 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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  40515 2620         .         .         .         .         .         .         .         .         .         .         .
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  40545 2640         .         .         .         .         .         .         .         .         .         .         .
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  40600 2650         .         .         .         .         .         .         .         .         .         .         .
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  40615 2660         .         .         .         .         .         .         .         .         .         .         .
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  40630 2670         .         .         .         .         .         .         .         .         .         .         .
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  40645 2680         .         .         .         .         .         .         .         .         .         .         .
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  40700 2690         .         .         .         .         .         .         .         .         .         .         .
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  40715 2700         .         .         .         .         .         .         .         .         .         .         .
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  40730 2710 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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  40745 2720         .         .         .         .         .         .         .         .         .         .         .
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  40800 2730         .         .         .         .         .         .         .         .         .         .         .
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  40815 2740         .         .         .         .         .         .         .         .         .         .         .
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  40830 2750         .         .         .         .         .         .         .         .         .         .         .
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  40845 2760         .         .         .         .         .         .         .         .         .         .         .
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  40900 2770         .         .         .         .         .         .         .         .         .         .         .
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  40915 2780         .         .         .         .         .         .         .         .         .         .         .
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  40930 2790         .         .         .         .         .         .         .         .         .         .         .
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  40945 2800         .         .         .         .         .         .         .         .         .         .         .
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  41000 2810 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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  41015 2820         .         .         .         .         .         .         .         .         .         .         .
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  41030 2830         .         .         .         .         .         .         .         .         .         .         .
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  41045 2840         .         .         .         .         .         .         .         .         .         .         .
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  41100 2850         .         .         .         .         .         .         .         .         .         .         .
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  41115 2860         .         .         .         .         .         .         .         .         .         .         .
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  41130 2870         .         .         .         .         .         .         .         .         .         .         .
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  41145 2880         .         .         .         .         .         .         .         .         .         .         .
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  41200 2890         .         .         .         .         .         .         .         .         .         .         .
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  41215 2900         .         .         .         .         .         .         .         .         .         .         .
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  41230 2910 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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  41245 2920         .         .         .         .         .         .         .         .         .         .         .
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  41300 2930         .         .         .         .         .         .         .         .         .         .         .
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  41315 2940         .         .         .         .         .         .         .         .         .         .         .
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  41330 2950         .         .         .         .         .         .         .         .         .         .         .
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  41345 2960         .         .         .         .         .         .         .         .         .         .         .
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  41400 2970         .         .         .         .         .         .         .         .         .         .         .
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  41415 2980         .         .         .         .         .         .         .         .         .         .         .
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  41430 2990         .         .         .         .         .         .         .         .         .         .         .
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  41445 3000---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.------
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RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

	OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
+	HYDROGRAPH AT									
+		EXAMPLE	18512.	17.50	9959.	3889.	1297.	40.00		

*** NORMAL END OF HEC-1 ***