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16. ABSTRACT

This report provides identification of desert hydrologic regions within the arid and semi-arid portions of California, as well as information and direction in choosing appropriate hydrologic and bulking methods specific to each identified desert region. The desert areas were divided into regions based on similar geographic, climate, and hydrologic characteristics. By using the information in this report, the engineer will be equipped in estimating proper desert hydrographs, peak flows, and sediment/debris loads, and have basis for defending these calculations in the project design process.

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IMPROVED HIGHWAY DESIGN METHODS FOR DESERT STORMS

FINAL REPORT - (Report No. CA07-0592)

Desert watershed near Borrego Springs

AUGUST 2007

California Department of Transportation
Division of Research and Innovation
1101 R Street
Sacramento, CA 95814
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Improved Highway Design Methods for Desert Storms

Final Report - (Report No. CA07-0592)

August 2007

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DISCLAIMER STATEMENT

EXECUTIVE SUMMARY

The California Department of Transportation (Caltrans) recognized the need for hydrologic methods that reflect the unique properties of California's desert storms. At the request of the Caltrans Division of Research and Innovation, the WEST Consultants study team has developed a suite of desert-specific hydrologic methods that will help to improve flow estimates used in culvert, bridge, and channel design. These methods will provide consistency in the estimation of desert hydrographs, bulking factors to reflect sediment and debris loads, and the subsequent flows used for sizing highway structures. With improved hydrologic methods as tools for project design, the engineer will have a basis for defending design and cost proposals to project managers, local agencies, and other interested parties.

The study team first investigated hydrologic and sediment/debris methods used by local, state, and Federal agencies in the desert environments of California, Nevada, Arizona, and New Mexico. Next, California's desert areas were divided into six regions based on similar geographic, climatic, and hydrologic characteristics:

1. Colorado Desert – includes Imperial Valley, Salton Sea, and Coachella Valley
2. Sonoran Desert – located southeast of the Mojave Desert region
3. Antelope Valley – located primarily in Los Angeles and Kern Counties
4. Mojave Desert – largest region, includes Mojave Valley and Death Valley
5. Owens Valley/Mono Lake – arid region on the leeward side of the Sierra Nevada
6. Northern Basin & Range – cold desert of northeastern California

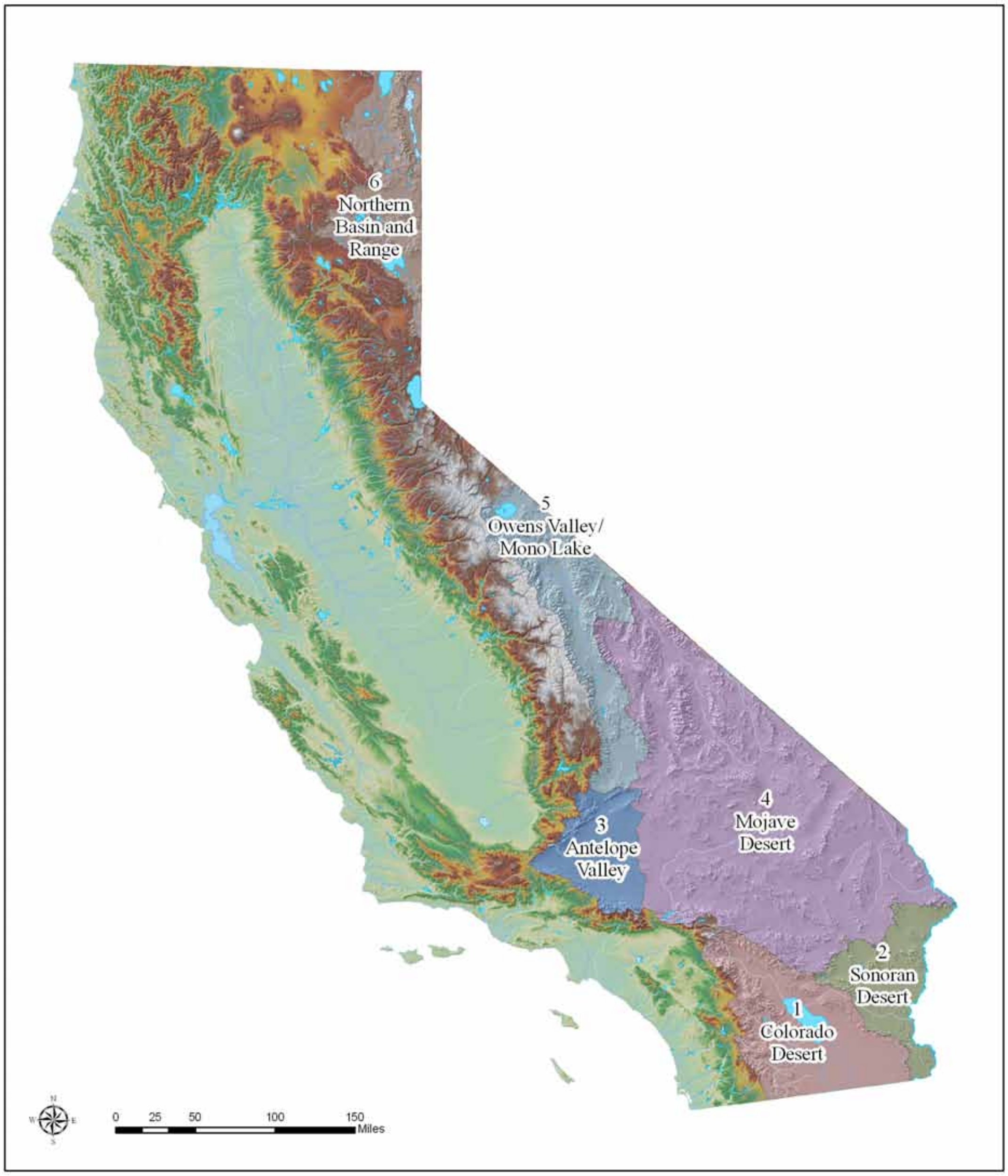
Desert Storms

Basic types of storms that can occur over California's desert regions are often classified as general winter storms, local thunderstorms, and general summer storms. General storms are usually of a frontal or convergence type that covers large areas (a front is a zone that separates two air masses, one of which is cooler than the other). Local storms are usually associated with convective activities and normally occur in the summer (convection is the vertical transport of heat and moisture in the atmosphere, typically caused by an unstable atmosphere). In the southern desert area, summer convective storms (thunderstorms) are generally dominant. In the northern part, general winter storms are the primary climatic factor that causes floods.

Flood-Frequency Analysis

There are a great variety of hydrologic methods that have been applied to the arid and semi-arid regions of California. They can be classified as three broad methods: flood-frequency analysis, regional regression equations, and rainfall-runoff simulation.

Although there are not many long records of annual peak flow data in the desert regions, the records represent valuable observed flood conditions for desert basins with a high variability in storms, soil conditions, and land use. Therefore, efforts should be made to make the maximum use of the observed data where available.



California's Desert Regions.

Regional Regression Equations

The current regional regression equations in USGS publications WSP 2433 and WRI 77-21 were found to be not representative of the watershed conditions in our desert study area. For this reason, the data set that was used to develop the USGS regression equations was reduced to a subset such that all selected stations have watershed characteristics similar to California's desert regions. New regression equations were then developed from the reduced data set. These equations can provide a good check on the reasonableness of peak discharges computed using rainfall-runoff simulation for an ungaged watershed.

One set of regional regression equations was developed for the southern desert regions (Colorado Desert, Sonoran Desert, Mojave Desert, and the Antelope Valley) based on a hybrid regional regression analysis. For the Owens Valley/Mono Lake and Northern Basin and Range regions, new sets of regional regression equations were developed using standard regression analyses. The new equations were found to produce better flow estimates than the equations found in the USGS publications. For the Northern Basin and Range, although the results were improved, there is still significant uncertainty associated with the new regression equations, and the development of a rainfall-runoff model may be preferable for ungaged watersheds in this region.

Rational Method

Given the assumptions of the Rational Method, an approximate upper limit of 160 acres (0.25 mi^2) is recommended for California's desert regions. Although this limit is approximate in nature, strong consideration should be given to selecting another more appropriate hydrologic method if the drainage area approaches or exceeds 160 acres.

Rainfall intensity-duration-frequency data used for the Rational Method can be obtained from either NOAA Atlas 14 (preferred where available) or DWR Bulletin No. 195. Runoff coefficients were provided for a number of typical desert terrain/vegetation types.

Rainfall-Runoff Simulation

Seven watersheds – one in each region plus an additional basin in the Mojave Desert region – were selected to test the rainfall-runoff methods believed to be the most applicable to California's desert regions. Test watersheds for each desert region were selected based on the availability of nearby peak streamflow and hourly precipitation data.

After the model parameters were selected and recorded rainfall-runoff events were simulated, each hydrologic model was then used to simulate a synthetic design storm to compute the 100-year peak discharge. The approach taken in the rainfall-runoff simulation was to treat the test watersheds as if they were ungaged, with the selection of appropriate model parameters based on readily available data for the watershed rather than performing true model calibration. Instead of calibration, the applicability of the hydrologic methods and parameters was validated by comparing rainfall-runoff computed flows to either observed values or those computed by flood-frequency analysis or using the new regional regression equations. A summary of the major findings from the rainfall-runoff simulation are provided below.

Infiltration Methods

- The Green and Ampt method greatly overestimated infiltration losses for the majority of test watersheds where it was applied, resulting in zero flow values in some cases.
- The SCS Curve Number method provided favorable results for the majority of watersheds and is recommended for use by Caltrans for desert hydrology studies.

Transformation Methods

- The San Bernardino County Mountain S-Graph is recommended for watersheds with mountainous terrain/high elevations in the upper portions.

- Simulation results using the San Bernardino County Desert S-Graph and Maricopa County Desert/Rangeland S-Graph were comparable.
- For the sake of consistency, the San Bernardino County Desert S-Graph is recommended for use in watersheds in the southern desert regions with limited or no mountainous terrain/high elevations.
- The USBR (1987) S-Graph is recommended for watersheds in the Northern Basin and Range.

Storm Duration and Temporal Distribution

- For watersheds in the southern desert regions with a drainage area less than 20 square miles, the 100-year, 6-hour Convective Storm (AMC I) provided favorable results and is recommended for use by Caltrans in estimating the 100-year peak discharge or other large flows.
- For watersheds greater than 20 square miles in the southern desert regions, both the 6-hour Convective Storm (AMC I) and the 24-hour General Storm (AMC II) should be analyzed and the larger of the two peak discharges selected.
- Watersheds along the Eastern Sierra in the Owens Valley/Mono Lake region are dominated by snowmelt-driven peaks. The use of regional regression equations is recommended where streamgage data are not available; otherwise, hydrologic modeling could be performed with snowmelt simulation, which is beyond the scope of this study.
- For the Northern Basin and Range region, the 100-year, 24-hour General Storm (AMC II) provided favorable results and is recommended for use by Caltrans in estimating the 100-year peak discharge or other large flows.

Recommendations for desert hydrology, including those for flood-frequency analysis, regional regression, and rainfall-runoff simulation, were summarized in the hydrology flowchart.

Sediment/Debris Bulking

While the bulking factor can be defined as a function of the sediment concentration, the expected concentration during a major flood event can only be estimated with significant uncertainty. As a result, the bulking factor should generally be considered a safety factor selected based on a combination of watershed data and engineering judgment, rather than a strictly computed value.

The bulking potential depends on the type of sediment-laden flow expected in the watershed, which may be determined by field reconnaissance, data collection, and consultation with local, State, and Federal agencies. Based on the information collected, engineering judgment and geomorphic experience should then be used to determine an appropriate bulking factor for the project. For hydraulic design, the main purpose of using bulked flows is to introduce a factor of safety when computing the required bridge opening or channel dimensions. Therefore, the selected bulking factor may not be strictly based on the expected maximum sediment concentration in the flow. A flow chart was developed that outlines the recommended bulking factor selection process.

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1 INTRODUCTION

1.1 Study Purpose

The California Department of Transportation (Caltrans) recognized the need for hydrologic methods that reflect the unique properties of California's desert storms. At the request of the Caltrans Division of Research and Innovation, the WEST Consultants study team has developed a suite of desert-specific hydrologic methods that will help to improve flow estimates used in culvert, bridge, and channel design. These methods will provide consistency in the estimation of desert hydrographs, bulking factors to reflect sediment and debris loads, and the subsequent flows used for sizing highway structures. With improved hydrologic methods as tools for project design, the engineer will have a basis for defending design and cost proposals to project managers, local agencies, and other interested parties.

1.2 Study Approach

This research study was divided into four phases:

Phase I:	Collect and Review Data
Phase II:	Determine Desert Hydrologic Regions and Applicability of Methods
Phase III:	Identify Representative Watersheds and Perform Analyses; Prepare Draft Report
Phase IV:	Prepare Final Report

The first part of Phase I was to investigate hydrologic methods used by local and state agencies in the desert environments of California, Nevada, Arizona, and New Mexico. In addition, hydrologic methods used by Federal agencies were analyzed. The second part of Phase I was to investigate methods used by local, state, and Federal agencies for predicting sediment and debris loads typical of desert watersheds, with an emphasis on bulking factors. The various data sources for Phase I are described in this chapter.

In Phase II, California's deserts were divided into regions based on their hydrologic, climatic, and related characteristics (Chapters 2 and 3). The applicability of various hydrologic methods are described in subsequent chapters: Flood-frequency Analysis and Regional Regression (Chapters 4-6), Rational Method (Chapter 7), and Rainfall-Runoff Simulation (Chapter 8).

In Phase III, representative test watersheds were identified for each of the desert regions (Chapter 9) and rainfall-runoff simulation was performed (Chapter 10). Finally, sediment/debris flows and bulking factors were analyzed (Chapter 11).

1.3 Data Sources

1.3.1 Local and State Agencies

Pertinent manuals and other publications from local and state agencies were obtained and reviewed, including those from:

Arizona:

- City of Tucson
- Coconino County (includes Flagstaff)
- Maricopa County (includes Phoenix)
- Pinal County
- Yavapai County
- Arizona Dept. of Transportation (ADOT)
- Arizona Dept. of Water Resources

California:

- Los Angeles County
- Riverside County
- San Bernardino County
- San Diego County
- California Department of Transportation (Caltrans)
- California Department of Water Resources (DWR)

Nevada:

- Clark County (includes Las Vegas)
- Nevada Dept. of Transportation (NDOT)
- Washoe County (includes Reno)

New Mexico:

- Albuquerque Metropolitan Arroyo Flood Control Authority

1.3.2 Federal Agencies

Relevant publications from Federal agencies were obtained and reviewed, including those from:

- U.S. Army Corps of Engineers (USACE)
- U.S. Geological Survey (USGS)
- Federal Emergency Management Agency (FEMA)
- Federal Highway Administration (FHWA)

- Natural Resources Conservation Service (NRCS)
- National Oceanic and Atmospheric Association (NOAA)
- U.S. Bureau of Reclamation (USBR)

1.3.3 Other Sources

Additional sources of data included:

- American Society of Civil Engineers (ASCE) Conference Proceedings
- ASCE Journal of Hydraulic Engineering and other relevant peer-reviewed journals
- Federal Inter-Agency Sedimentation Conference Proceedings

1.4 Desert Hydrology Database

A Microsoft® Access database (2000 file format) was developed to store data relevant to the study, including bibliographic information for each reference.

Bibliographic data for each reference include:

- Title, subtitle, and publication number
- Author and publisher (or agency)
- Publication month and year
- Journal articles: volume, number, and pages
- URL (if reference is available online)
- Category and keywords
- Summary/abstract

The references in the database can be queried by Title, Author, and Keyword. The database includes references located and reviewed during Phase I of the study; references obtained during later phases of this study have not been added to the database. A printout of the database summaries/abstracts is provided in Appendix A.

1.5 Interviews

Telephone and/or in-person interviews were conducted with qualified agency personnel from local, state, and Federal agencies. In particular, Caltrans District hydrologists or hydraulic engineers were contacted to see what guidance is currently being used for hydrologic design. Interview summaries are provided in Appendix A.

1.6 Acknowledgments

Martin J. Teal, P.E., P.H., served as WEST Consultants project manager. Jake Gusman, P.E., served as assistant project manager. Dr. Henry Hu, P.E., had a primary role in developing the rainfall-runoff simulation approach. Kurt Baron provided Geographic Information Systems (GIS) services. Christy Warren, P.E., performed hydrologic modeling of the test watersheds. Dr. Hu and John Howard conducted the regression analysis. Dr. Brian Wahlin, P.E., assisted with data collection and review and preparation of the Phase I report. Dr. Jeffrey Bradley, P.E., provided insight regarding sediment/debris bulking factors.

Cathy C. Avila, P.E., of Avila & Associates performed data collection, communication/coordination with agencies, and QA reviews of study reports.

Bruce D. Swanger, P.E., served as Caltrans project manager for the study, providing valuable assistance and direction. Glenn S. DeCou, P.E. served as Chief of the Office of State Highway Drainage Design, Caltrans HQ Division of Design. Andrew Brandt, P.E. (District 9) and Karen Jewel, P.E. (District 11) served on the study review team.

2 DESERT REGIONS

As illustrated in the Figure 2-1, California's desert areas have been divided into six regions based on similar geographic, climatic, and hydrologic characteristics:

1. Colorado Desert – includes Imperial Valley, Salton Sea, and Coachella Valley
2. Sonoran Desert – located southeast of the Mojave Desert region
3. Antelope Valley – located primarily in Los Angeles and Kern Counties
4. Mojave Desert – largest region, includes Mojave Valley and Death Valley
5. Owens Valley/Mono Lake – arid region on the leeward side of the Sierra Nevada
6. Northern Basin & Range – cold desert of northeastern California

2.1 Geospatial Data

Geospatial data used to develop the desert region boundaries included:

- Hydrologic/watershed and regional flood frequency boundaries
- Ecologic regions
- Topographic, vegetation, and soils data
- Climatic data (precipitation, temperature)

Table 2-1 provides a full list of data types and sources.

2.2 Desert Regions – Boundary Delineation

The California Department of Water Resources (DWR) hydrologic regions, planning areas, and detailed analysis units served as the overall template for delineating the desert region boundaries. The DWR detailed analysis units were considered the smallest possible division for the purpose of delineating desert regions. The data listed in Table 2-1 and shown in Appendix B were used to determine where the boundaries should be drawn. The appropriate detailed analysis units were then combined to form each region. A brief discussion of each desert region, including major reasons why its boundaries were drawn as proposed, is provided below.

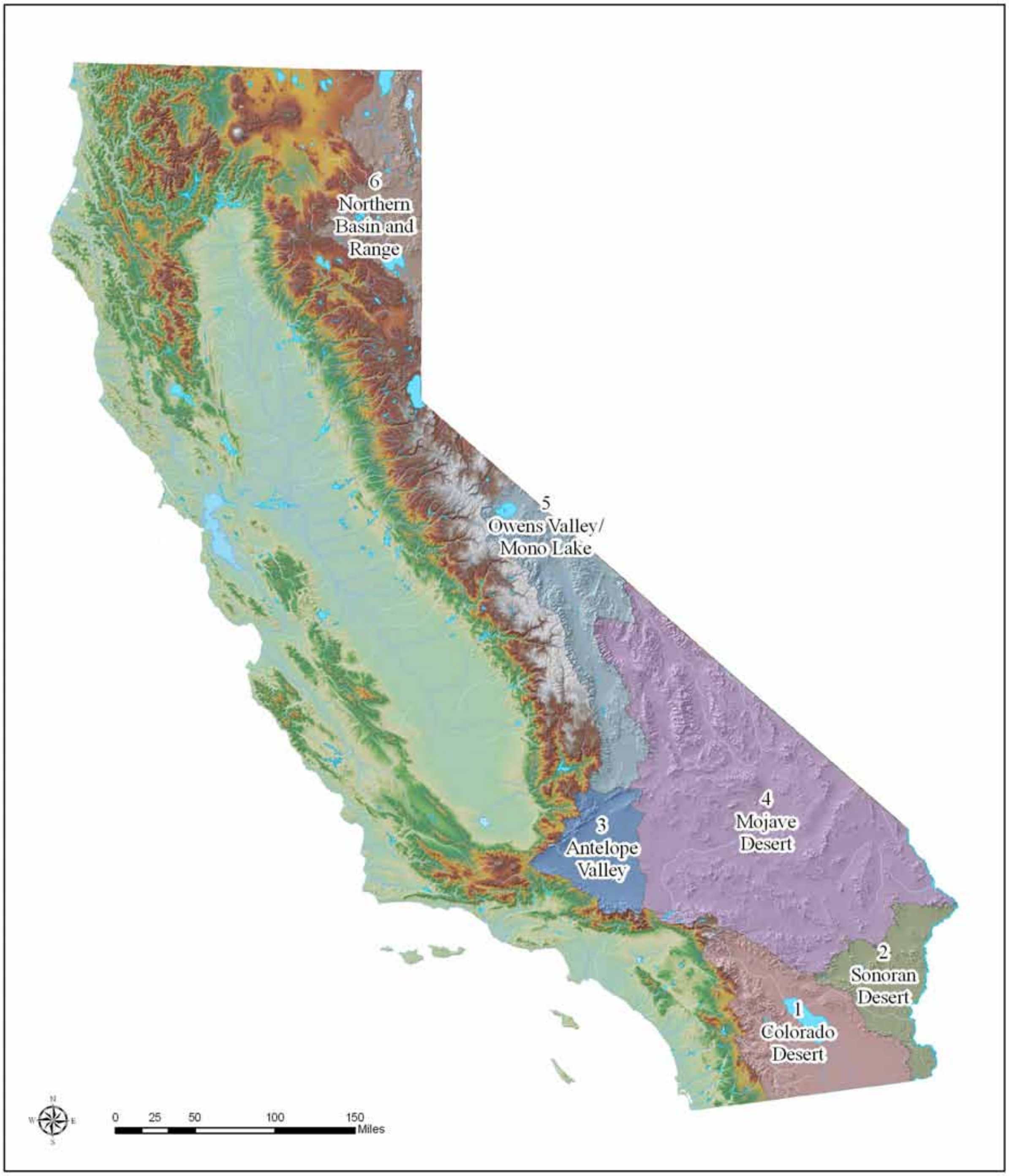


Figure 2-1. Proposed Desert Regions.

Table 2-1. GIS Data for Caltrans Desert Hydrology Study.

	Type/Name	**Agency/Source**
Regional Boundaries	DWR Hydrologic Regions, Planning Areas, and Detailed Analysis Units	California Dept. of Water Resources (DWR)
	Flood Frequency Regions - Southwestern U.S.	USGS
	Flood Frequency Regions - California	USGS
	Geomorphic Provinces	California Geological Survey
	Modified Köppen Climate System	California Dept. of Fish & Game (DFG)
	Precipitation Limits - Convective vs. General	NOAA Atlas 14
	Level III Ecoregions	U.S. Environmental Protection Agency
	Ecoregions of the U.S.	U.S. Forest Service (USFS)
	CA Bioregions	California Dept. of Fish & Game (DFG)
Topographic & Climatic Data	Digital Elevation Model	USGS
	Vegetation Coverage	GAP Analysis Project (Davis *et al.*, 1998)
	Hydrologic Soil Groups	USDA/NRCS STATSGO
	Reference Evapotranspiration	California Irrigation Management Information System (CIMIS)
	Mean Annual Precipitation	California Dept. of Forestry & Fire Protection
	Reference Evapotranspiration *minus* Mean Annual Precipitation	Computed
	Mojave Summer Precipitation	Mojave Desert Ecosystem Program
	Mojave Winter Precipitation	Mojave Desert Ecosystem Program
	Average Max. Temperature of Warmest Month	Oregon Climate Service
	Average Min. Temperature of Coolest Month	Oregon Climate Service
	Maximum Recorded Peak Discharge divided by Drainage Area	USGS

2.2.1 Desert Region 1 – Colorado Desert

The Colorado Desert region, which is considered a distinct geomorphic province by the California Geological Survey, is a low-elevation basin that has been historically impacted by Colorado River flooding. Silt deposits from the ancient Lake Cahuilla – created and sustained by periodic flooding – characterize a region that includes the Imperial and Coachella Valleys and is now dominated by the Salton Sea (California Geological Survey, 2002).

According to Hromadka (1996), there is a distinct difference in flood frequency tendencies between the arid regions of San Bernardino County (i.e., the Mojave Desert) and those of Riverside and San Diego Counties, which form much of the Colorado Desert region (note: Imperial County was not specifically included in Hromadka's study area). The approximate division is the Latitude 34 degrees north.

2.2.2 Desert Region 2 – Sonoran Desert

The specific names for Desert Regions 1 and 2 (Colorado vs. Sonoran Desert) were obtained from the USFS ecoregions. The area encompassing the two regions is often combined in other references, and the single region is referred to as either the Colorado or Sonoran Desert.

From a hydrologic perspective, however, the Sonoran Desert region appears to be distinct from the Colorado Desert region. The characteristics of stream gage sites throughout the desert areas of California were compiled as part of a USGS (1997a) study to develop new flood frequency equations for the southwestern U.S. WEST Consultants created a geospatial data layer corresponding to the maximum-recorded peak discharge at each gage site, divided by drainage area above the gage. On average, the maximum-recorded peak discharge ratio in the Sonoran Desert region is significantly larger than in any other region.

2.2.3 Desert Region 3 – Antelope Valley

Antelope Valley, which is located primarily in Los Angeles and Kern Counties, is on the leeward side of the Transverse Ranges and the Tehachapi Mountains. While the Antelope Valley is considered part of the overall Mojave Desert, it is considered a separate region for the purpose of this study.

Chapter 810 of the Caltrans Highway Design Manual includes regional flood frequency equations from the USGS report "Magnitude and Frequency of Floods in California" (USGS, 1977). The state is divided into six flood frequency regions. All of the California deserts (apart from the arid region in northeastern CA) are covered by a single region – the "South Lahontan-Colorado Desert." However, Wang and Dawdy (1990) concluded that the South Lahontan-Colorado Desert Region should be split into at least three sub-regions based on plots of peak flood data versus drainage area: one for Antelope Valley, one for Owens Valley, and one covering the remaining portion of the region.

Flood frequency equations with lower standard error values were developed specifically for the Antelope Valley, which was the focus of the study by Wang and Dawdy. In addition, the USGS studied the precipitation depth, duration, and frequency characteristics of the Antelope Valley (Blodgett, 1995). The studies that have already been completed are a major reason for separating the Antelope Valley into its own region.

It should be noted that Desert Region 3 also includes additional area north of the Antelope Valley that appears to have more in common with the Antelope Valley region than the Owens Valley/Mono Lake region (Desert Region 5).

2.2.4 Desert Region 4 – Mojave Desert

The Mojave Desert is the largest of the six desert regions in this study. The driest of the North American deserts, the Mojave does not receive as much summer rainfall as the Sonoran/Colorado Desert to the south, and receives much less winter precipitation than the Great Basin Desert to the north. The California Geological Survey (2002) describes the area as a "broad interior region of isolated mountain ranges separated by expanses of desert plains."

2.2.5 Desert Region 5 – Owens Valley/Mono Lake

The Owens Valley is a long, slender valley located on the leeward side of the Sierra Nevada, and just west of the White and Inyo Mountains. The Mono Lake basin is located northwest of the Owens Valley and is also leeward of the Sierra Nevada.

As described for Desert Region 2, the maximum-recorded peak discharge divided by drainage area was computed for USGS stream gages throughout the study area. The gages in the Owens Valley/Mono Lake region consistently exhibited smaller ratios of peak discharge to drainage area than any other region.

2.2.6 Desert Region 6 – Northern Basin & Range

A single region has been delineated for the cold desert area of northeastern California. Much of this region is considered part of the Northern Basin & Range, which is the westernmost part of the Great Basin Desert. The rest of region is on the Modoc Plateau – a high elevation, volcanic table land (California Geological Survey, 2002).

Desert Region 6, which is dominated by sagebrush shrub land, includes the Honey Lake basin, Warner Mountains, and the Upper, Middle, and Lower Alkali Lakes. This desert region is characterized by much lower average temperatures than the southern desert regions of California.

3 DESERT STORMS

Before determining which hydrologic and sediment/debris methods are applicable to California's desert areas, the types of storms affecting these regions need to be identified. The types and characteristics of desert storms are described in this chapter.

Basic types of storms that can occur over California's desert regions are often classified as general winter storms, local thunderstorms, and general summer storms, although some individual storms may consist of a combination of types. General storms are usually of a frontal or convergence type that covers large areas (a front is a zone that separates two air masses, one of which is cooler than the other). Local storms are usually associated with convective activities and normally occur in the summer (convection is the vertical transport of heat and moisture in the atmosphere, typically caused by an unstable atmosphere).

3.1 Seasonal Occurrence of Peaks

Annual peak flow data at USGS stream-gaging stations within the six desert regions were analyzed for the season in which each annual peak occurred. The locations of these gaging stations, as well as gage summaries, are included in Appendix C. The peak flow data include records at gaging stations with less than 10 years of record. All peaks that were affected to a known or unknown degree by regulation or diversion were not included in the analysis. All peaks due to dam failure, canal operation, or affected by urbanization, mining, etc. were also not included.

Table 3-1 shows the seasonal distribution of all annual peaks on unregulated natural streams for each desert region. The winter, spring, summer, and fall seasons are defined as months of January through March, April through June, July through September, and October through December, respectively. Table 3-2 shows the seasonal distribution of large peaks with the unit discharge (the reported discharge divided by the drainage area) equal to or greater than 100 cfs per square mile for the southern regions (Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert) and 20 cfs per square mile for the northern regions (Owens Valley/Mono Lake and Northern Basin and Range). Because the drainage area for some stations was not reported in the USGS database, these stations were not included in the analysis of large peaks. Table 3-1 and Table 3-2 provide a good indication of the spatial and seasonal distribution of floods and storms in the study area.

3.2 General Winter Storms

A significant portion of the normal annual precipitation occurs during the cool season, primarily from November through early April, as mid-latitude cyclones from the North Pacific Ocean occasionally move across the west coast of the United States to bring significant precipitation to central and southern California, with some spill-over precipitation reaching the interior desert areas (see Figure 3-1). The percentage of winter storms and runoff in the study areas is directly related to the distance of the desert region from the moisture source (the Pacific Ocean). Significantly more runoff events occurred during the winter storm months in the Northern Basin and Range, Antelope Valley, and Colorado Desert regions than in the interior Mojave Desert, Sonoran Desert, and Owens Valley/Mono Lake regions (see Table 3-1).

Most of these cool-season storms are of the general winter type, in which steady precipitation typically falls for 6 to 12 hours or more, and perhaps intermittently for 3 to 5 days over relatively large areas. In the mountains that rise out of the deserts, significantly greater precipitation normally falls from these storms than occurs on the valley floor, and a greater percentage of the normal annual precipitation occurs during the winter months than is observed at the desert stations.

At elevations above 6,000 feet, much of the winter precipitation falls as snow. Snowfall and snowmelt are not significant factors in the generation of flood-producing runoff in the southern portion of the study area (Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert). In the northern semi-arid regions (Owens Valley/Mono Lake and Northern Basin and Range), more floods from snowmelt occur at lower elevation. The Owens Valley/Mono Lake region is located on the eastern side of the Sierra Nevada. More than 50 percent of runoff events occurred in spring, likely due to snowmelt (Table 3-1). However, snowmelt usually did not produce large floods (Table 3-2).

General winter storms produce the majority of large peaks in the northern semi-arid areas. The majority of the largest peaks with unit discharge greater than or equal to 20 cfs per square mile occurred during winter and fall months in the Owens Valley/Mono Lake and Northern Basin and Range regions (Table 3-2).

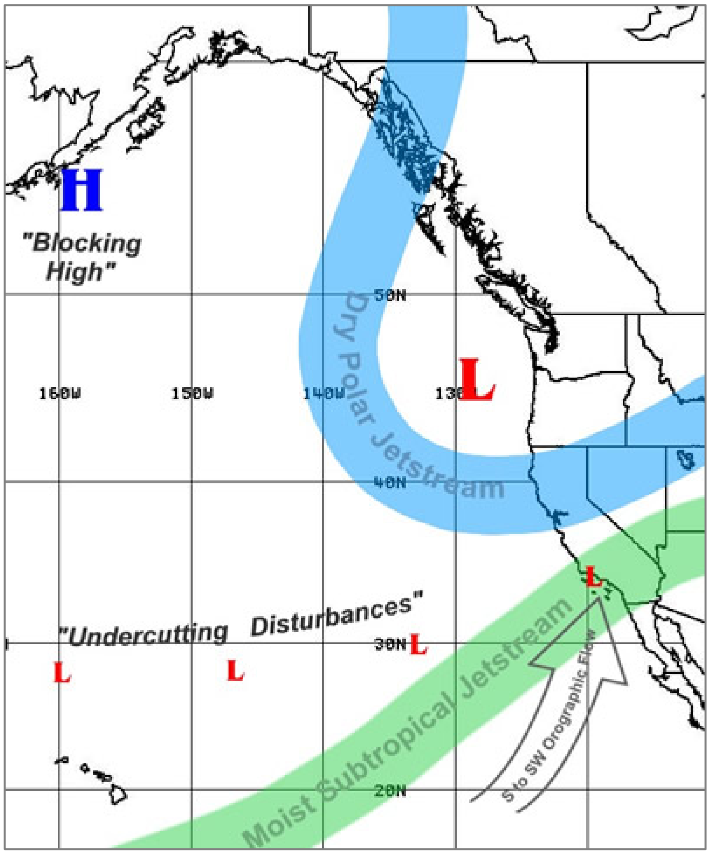


Figure 3-1. Example General Winter Storm Pattern (January 2005, www.cnrfc.noaa.gov).

Table 3-1. Seasonal Distribution of All Annual Peaks.

Desert Region	**Winter** (Jan – Mar)		**Spring** (Apr – June)		**Summer** (July – Sept)		**Fall** (Oct – Dec)		**Undefined** (year given for peak, not month)
	Number of peaks	**Percentage of peaks (%)**	**Number of peaks**	**Percentage of peaks (%)**	**Number of peaks**	**Percentage of peaks (%)**	**Number of peaks**	**Percentage of peaks (%)**	
1. Colorado	280	41	37	5	242	35	132	19	56
2. Sonoran	12	12	3	3	61	61	24	24	28
3. Antelope	199	51	56	14	33	9	99	26	72
4. Mojave	217	36	45	7	240	39	107	18	156
5. Owens	54	11	275	55	136	27	37	7	47
6. Northern	241	57	142	33	7	2	35	8	18

Table 3-2. Seasonal Distribution of Large Peaks.

Desert Region	**Winter** (Jan – Mar)		**Spring** (Apr – June)		**Summer** (July – Sept)		**Fall** (Oct – Dec)		**Total number of large peaks**
	Number of peaks	**Percentage of peaks (%)**	**Number of peaks**	**Percentage of peaks (%)**	**Number of peaks**	**Percentage of peaks (%)**	**Number of peaks**	**Percentage of peaks (%)**	
1. Colorado	6	15	1	3	25	64	7	18	39
2. Sonoran	5	10	0	0	33	63	14	27	21
3. Antelope	22	58	3	8	4	11	9	24	24
4. Mojave	39	32	5	4	58	48	20	16	122
5. Owens	5	38	0	0	5	38	3	23	13
6. Northern	47	68	10	14	0	0	12	17	69

Note: Large peak is defined as unit discharge ≥ 100 cfs/square mile for Regions 1 through 4, ≥ 20 cfs/square mile for Regions 5 and 6.

3.3 Local Thunderstorms (Convective Precipitation)

Local thunderstorms can occur in California's desert areas, especially in the southeastern area, at any time of the year, but are most common and most intense during the summer months, primarily from June to September. They develop as warm, moist tropical air drifts northward and northwestward from Mexico and the Gulf of California, and are sometimes enhanced by moisture and atmospheric circulation drifting northward from tropical storms off the west coast of Baja California. These local thunderstorms can produce very heavy rain for short periods of time over small areas, causing very rapid runoff from small drainages. The result may be flash floods, which can lead to loss of life and substantial property damage. Table 3-2 indicates that a significant percentage of the largest peaks for the Colorado Desert, Sonoran Desert, and Mojave Desert regions occurred in summer. They were likely caused by summer thunderstorms over small basins with a drainage area generally less than 20 square miles.

3.4 General Summer Storms

General summer storms in the semi-arid and arid areas of California are quite rare. However, on occasion a tropical storm from off the west coast of Baja California can drift far enough northward to bring rain, occasionally heavy, sometimes with very heavy thunderstorms embedded. The season in which these storms are the most likely to significantly affect southern California is mid-August through early October.

3.5 NOAA Precipitation Regions

The evaluation of the areal and seasonal distributions of peak flow population and the associated storm types clearly indicate that there are two distinct regions in California's semi-arid and arid areas, each of which has a different dominant precipitation pattern. In the southern desert area, summer convective storms (thunderstorms) are generally dominant. In the northern part, general winter storms are the primary climatic factor that causes floods. This areal and seasonal distribution of peak flow data is generally consistent with the dominant storm type delineation by NOAA (Bonnin et. al, 2004). NOAA divided southern California and the eastern half of northern California into a general precipitation area and a convective precipitation area. Figure 3-2 shows these NOAA-delineated regions, the desert regions from the current study, and the DWR detailed analysis units.

One discrepancy between the NOAA precipitation regions and the seasonal distribution of peak flow data was found in the Antelope Valley. Table 3-1 and Table 3-2 indicate that the majority of the Antelope Valley peak flow events and its largest peaks occurred in winter and fall. However, NOAA had classified this region as a convective precipitation dominant area. The USGS stream-gaging stations in the Antelope Valley are not evenly distributed throughout the region, as shown in Figure 3-3. There are only a few stations on the east side of the region, which has a more arid environment. A significant number of stations are located near the southwestern perimeter of the region in the San Gabriel Mountains, which receives more moisture. Therefore, the current analysis using peak flow data does not reflect the overall flood conditions in the region. NOAA used the long-record precipitation data directly to delineate the precipitation pattern. Therefore, the NOAA delineation is considered more representative of hydrologic conditions in the Antelope Valley.

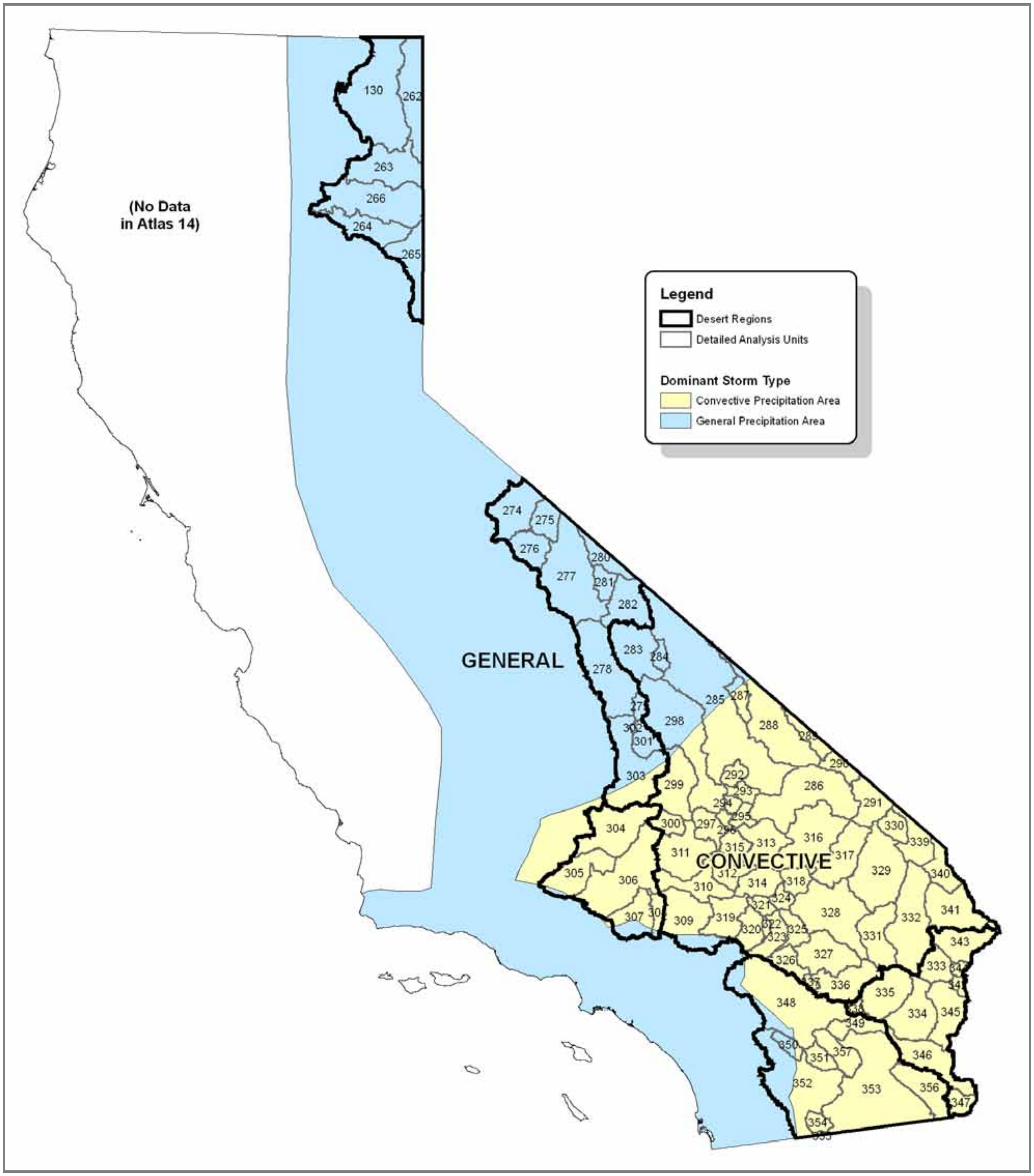


Figure 3-2. NOAA Boundary of Convective and General Precipitation Limits.

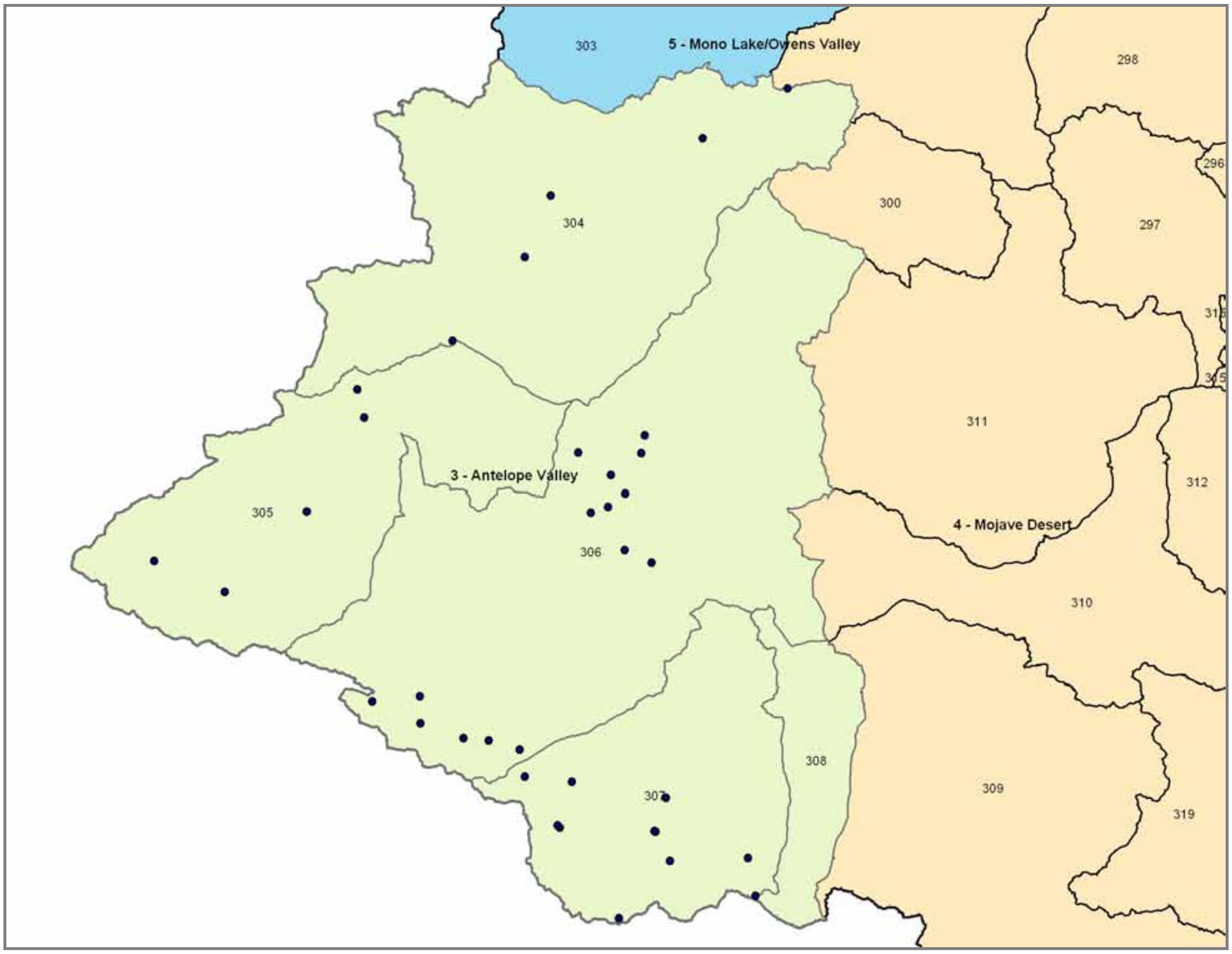


Figure 3-3. Locations of USGS Gaging Stations in Antelope Valley.

4 FLOOD-FREQUENCY ANALSYIS

There are a great variety of hydrologic methods that have been applied to the arid and semi-arid regions of California. They can be classified as three broad methods: flood-frequency analysis, regional regression equations, and rainfall-runoff simulation. This chapter describes flood-frequency analysis while regional regression and rainfall-runoff simulation are described in subsequent chapters.

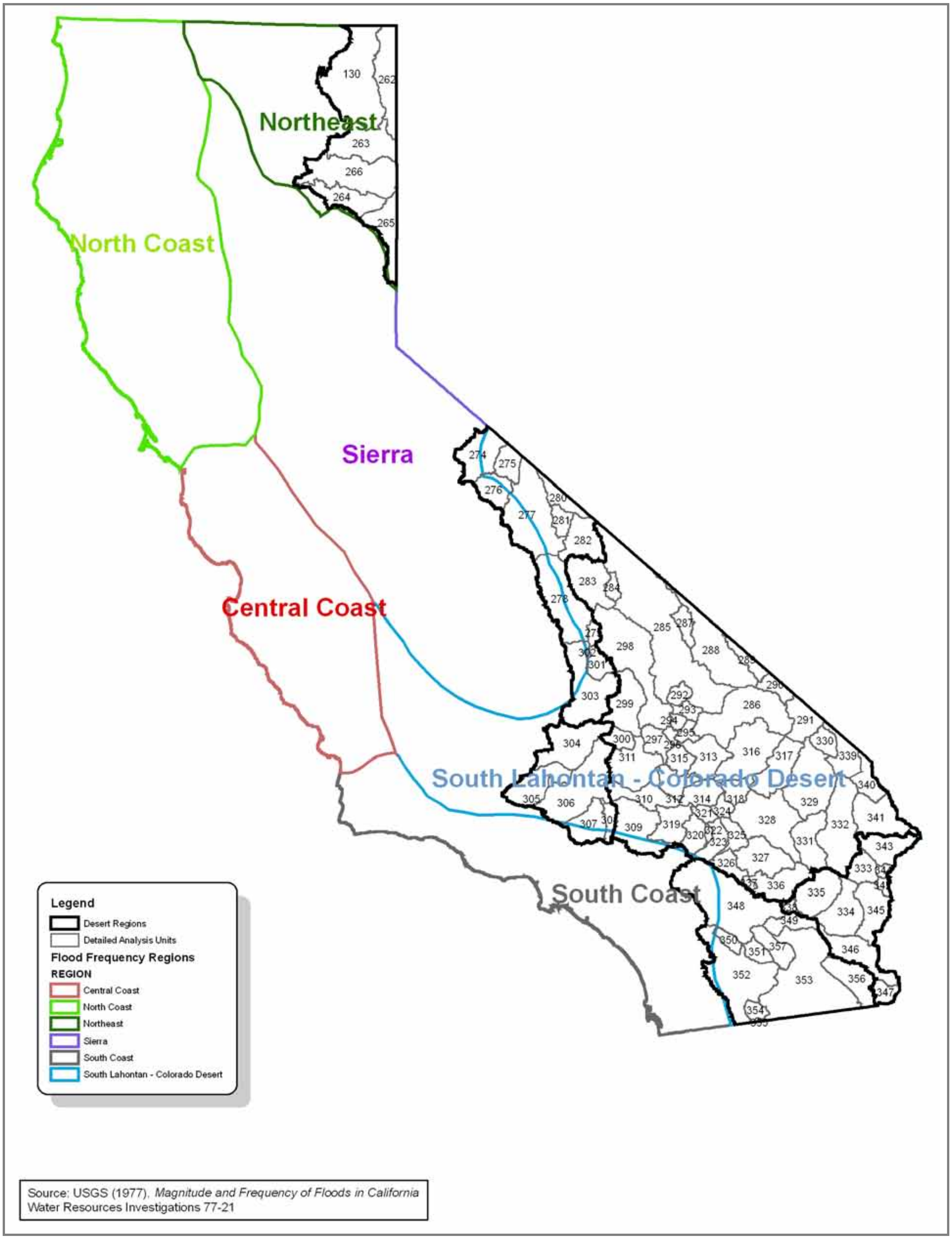
4.1 USGS Flood-Frequency Reports

A statistical flood-frequency analysis can be performed on gaged catchments with long periods of streamflow records. This is typically done by fitting a theoretical probability distribution to observed annual peaks. Many agencies recommend the use of the methodology presented in Bulletin 17B, "Guidelines for Determining Flood Flow Frequency" (Interagency Advisory Committee on Water Data, 1982) to perform a flood-frequency analysis. There are two main USGS reports that include flood-frequency flows for many stations in the desert areas: Water Supply Paper (WSP) 2433 – *Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States* (USGS, 1997a) and Water Resources Investigations (WRI) 77-21 – *Magnitude and Frequency of Foods in California* (USGS, 1977).

In WRI 77-21, the flood-frequency flows were based on annual peak flow data through 1973. There are two regions that cover the desert areas: the Northeast region and the South Lahontan-Colorado Desert region (Figure 4-1). In WSP 2433, the majority of the peak flow data came from drainage areas of less than about 200 mi^2 and mean annual precipitation less than 20 inches in a large study area, encompassing most of the arid lands of the southwestern United States. The individual sites had at least 10 years of record through Water Year 1986. Three regions (Regions 5, 6, and 10) cover the desert areas in southern California (Figure 4-2). Region 2 includes a small portion of the Northern Basin and Range region. If a gaging station was used in both studies, the flood-frequency flows included in WSP 2433 should be used since this report used a longer period of record.

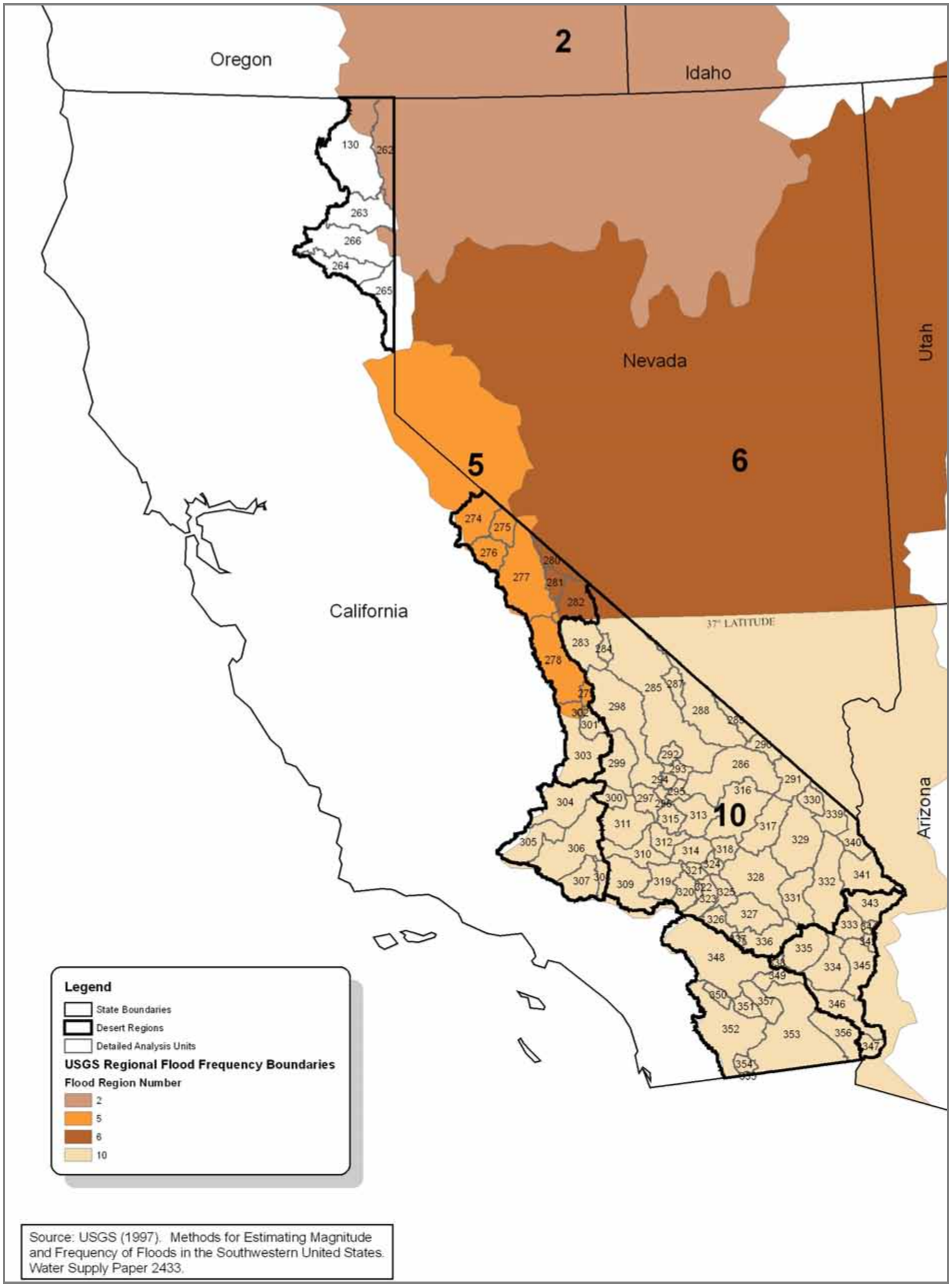
4.2 Years with Zero Flow

If a gaging station has a long period of record, the flood-frequency analysis generally can produce reliable estimation of frequency flows. However, in arid regions, long periods of streamflow records are typically not available. Table 4-1 shows the summary of peak flow data in each desert region. Except for Region 1 (Colorado Desert), the average years of record only range from 11 to 18 years. In addition, the data records at many gaging stations have many years of zero flows due to the nature of intermittent or ephemeral streams. For example, in the Mojave Desert and Sonoran Desert regions, more than 20 percent of the annual peaks are zero flows (Table 4-1). Because of the extreme variability in land uses, soil types, and rainfall patterns in the arid regions, flood-frequency relations at many stations are typically undefined or unreliable if fitted with a theoretical distribution, such as the log-Pearson Type III distribution (Hjalmarson and Thomas, 1992). As a result, a flood-frequency analysis cannot be performed for the majority of desert watersheds. Nevertheless, the peak flow records available at sporadic gaging stations provide valuable data for not only determining reasonable flood-frequency relations at these gaged streams, but also comparing the flood-frequency estimates with flows determined using other methods.



Source: USGS (1977). *Magnitude and Frequency of Floods in California* Water Resources Investigations 77-21

Figure 4-1. Relationship between Proposed Desert Regions and Flood Regions in WRI 77-21.



Source: USGS (1997). Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States. Water Supply Paper 2433.

Figure 4-2. Relationship between Proposed Desert Regions and Flood Regions in WSP 2433.

Table 4-1. Summary of Peak Flow Data in Desert Regions.

Desert Region	Number of UGSS stations	Total station-years	Average years of record	Total station-years with flow larger than zero	Total station-years with zero flow	Percentage of years with zero flow
1. Colorado	36	747	21	687	60	8.0
2. Sonoran	12	128	11	99	29	22.7
3. Antelope	35	459	13	389	70	15.3
4. Mojave	42	765	18	608	157	20.5
5. Owens	41	549	13	509	40	7.3
6. Northern	34	443	13	428	15	3.4

USGS Water-Supply Paper (WSP) 1543-A – *Flood-Frequency Analyses* (USGS, 1960) was also reviewed; however, it describes the methodology only but does not provide flood-frequency relations for California's desert regions. Moreover, it has been largely superseded by later USGS publications (WRI 77-21 and WSP 2433).

4.3 Recommended Approach

Although there are not many long records of annual peak flow data in the desert regions, the records represent valuable observed flood conditions for desert basins with a high variability in storms, soil conditions, and land use. Efforts should be made to make the maximum use of the observed data. Recommended procedures are as follows:

- If there are two gaged sites that have similar watershed characteristics but one has a short record and the other has a longer record of peak flows, a two-station comparison analysis can be conducted to extend the equivalent length of records at the short-term gaged site given that the two stations have sufficient highly correlated concurrent peaks. WRI 77-21 (USGS, 1977) and the U.S. Army Corps of Engineers Engineering Manual 1110-2-1415 (USACE, 1993) provide details about the procedures for a two-station analysis.

- At a gaged site, weighted estimates of peak discharges based on the station flood-frequency relation and the regional regression equations are considered the best estimates of flood frequency and are used to reduce the time-sampling error that may occur in a station flood-frequency estimate (USGS, 1997a).

- Flood-frequency relations at sites near gaged sites on the same stream can be estimated using a ratio of drainage area for the ungaged and gaged sites. The drainage-area ratio should be approximately between 0.5 and 1.5 (USGS, 1997a). Watershed characteristics of the ungaged and gaged drainage basins should be similar. WSP 2433 recommends the following equation:

$$Q_{T(u)} = Q_{T(g)} \left(\frac{A_u}{A_g} \right)^x \qquad (4.1)$$

where

$Q_{T(u)}$ = peak discharge (in cfs) at ungaged site for T-year recurrence interval,

$Q_{T(g)}$ = weighted discharge (in cfs) at gaged site for T-year recurrence interval,

A_u = drainage area (in mi^2) at ungaged site,

A_g = drainage area (in mi^2) at gaged site,

x = exponent for each region in accordance with Table 4-2.

Table 4-2. Exponent in Equation 4.1 for Each WSP 2433 Region.

Flood Region Name	**USGS Flood Region Number**	**Exponent (*x*)**
Northwest	2	0.7
Eastern Sierra	5	0.8
Northern Great Basin	6	0.6
Southern Great Basin	10	0.6

- The flood-frequency flows and the maximum peak discharges at several stations in a region should be used whenever possible to compare the flood-frequency estimates at an ungaged site determined from a rainfall-runoff approach or regional regression equations. The watershed characteristics at the ungaged and gaged sites should be similar.

These methods can provide good results where observed data are available and the criteria (e.g., similar drainage area ratio) are met.

5 REGIONAL REGRESSION: USGS EQUATIONS

For ungaged streams, estimating discharge is normally performed using a regional statistical (regression) analysis of flood-frequency flows based on streamflow records collected at gaging stations or a deterministic rainfall-runoff model that computes the runoff from design storms. Described in this chapter are regional regression equations developed by the USGS.

5.1 USGS Regression Equations

In the study area, regional regression equations were developed in both USGS WRI 77-21 and WSP 2433. The Highway Design Manual (HDM, Caltrans, 2006) lists these regression equations in Figures 819.2C and 819.2D, which are included below as Figure 5-1 and Figure 5-2, respectively (note: WSP 2433 expands on Open File Report 93-419, which was referenced in the HDM).

For areas that were covered in both USGS studies (Figure 4-1 and Figure 4-2), the regression equations in WSP 2433 were considered more reliable for the following reasons:

- Longer period of peak flow records. WSP 2433 used annual peak data through Water Year 1986. WRI 77-21 used annual peak data through Water Year 1973.

- Additional peak flow gages. Some gaging stations were not used in WRI 77-21 because they did not have 10 or more years of data.

- A better multiple-regression approach. WSP 2433 used generalized least-squares (GLS) regression analyses in Regions 2, 5, and 6 (Figure 4-2). GLS takes into account the possible cross correlation and unequal variance of flood-frequency estimates at gaged sites. In Region 10, a hybrid analysis (Hjalmarson and Thomas, 1992), which combined elements of the station-year method and multiple-regression analysis, was applied and used because in this region the standard multiple-regression method was inadequate. Individual flood-frequency relations developed using a flood-frequency analysis at gaged sites were not used. Instead, all annual peaks from all gaging stations that had at least 10 years of record were combined into one composite data set.

In a flood insurance study, the regression analysis method is preferred by FEMA over the rainfall-runoff approach (Federal Emergency Management Agency, 2003a). FEMA recommends the use of the most recent regional regression equations published by USGS, if these equations are applicable for the studied streams. Where regional regression equations are not applicable due to special watershed characteristics, FEMA recommends the use of a rainfall-runoff model. As described in the next section, the USGS regional regression equations are likely not applicable to many desert washes, especially in southern California, because generally they are not very representative of the flood conditions in the desert areas.

It should be noted that during the analysis, the USGS regression equations for WSP 2433 Region 5 included in the current Highway Design Manual (see Figure 5-2) were found to contain an error. The exponents to the elevation term (ELEV/1,000) are missing.

NORTH COAST REGION(2)

$Q_2 = 3.52\ A^{0.90}\ p^{0.89}\ H^{-0.47}$

$Q_5 = 5.04\ A^{0.89}\ p^{0.91}\ H^{-0.35}$

$Q_{10} = 6.21\ A^{0.88}\ p^{0.93}\ H^{-0.27}$

$Q_{25} = 7.64\ A^{0.87}\ p^{0.94}\ H^{-0.17}$

$Q_{50} = 8.57\ A^{0.87}\ p^{0.96}\ H^{-0.08}$

$Q_{100} = 9.23\ A^{0.87}\ p^{0.97}$

NORTHEAST REGION(3)

$Q_2 = 22\ A^{0.40}$

$Q_5 = 46\ A^{0.45}$

$Q_{10} = 61\ A^{0.49}$

$Q_{25} = 84\ A^{0.54}$

$Q_{50} = 103\ A^{0.57}$

$Q_{100} = 125\ A^{0.59}$

SOUTH LAHONTAN-COLORADO DESERT REGION(3)

$Q_2 = 7.3\ A^{0.30}$

$Q_5 = 53.0\ A^{0.44}$

$Q_{10} = 150\ A^{0.53}$

$Q_{25} = 410.0\ A^{0.63}$

$Q_{50} = 700.0\ A^{0.68}$

$Q_{100} = 1080.0\ A^{0.71}$

SIERRA REGION

$Q_2 = 0.24\ A^{0.88}\ p^{1.58}\ H^{-0.80}$

$Q_5 = 1.20\ A^{0.82}\ p^{1.37}\ H^{-0.64}$

$Q_{10} = 2.63\ A^{0.80}\ p^{1.25}\ H^{-0.58}$

$Q_{25} = 6.55\ A^{0.79}\ p^{1.12}\ H^{-0.52}$

$Q_{50} = 10.4\ A^{0.78}\ p^{1.06}\ H^{-0.48}$

$Q_{100} = 15.7\ A^{0.77}\ p^{1.02}\ H^{-0.43}$

CENTRAL COAST REGION

$Q_2 = 0.0061\ A^{0.92}\ p^{2.54}\ H^{-1.10}$

$Q_5 = 0.118\ A^{0.91}\ p^{1.95}\ H^{-0.79}$

$Q_{10} = 0.583\ A^{0.90}\ p^{1.61}\ H^{-0.64}$

$Q_{25} = 2.91\ A^{0.89}\ p^{1.26}\ H^{-0.50}$

$Q_{50} = 8.20\ A^{0.89}\ p^{1.03}\ H^{-0.41}$

$Q_{100} = 19.7\ A^{0.88}\ p^{0.84}\ H^{-0.33}$

SOUTH COAST REGION

$Q_2 = 0.14\ A^{0.72}\ p^{1.62}$

$Q_5 = 0.40\ A^{0.77}\ p^{1.69}$

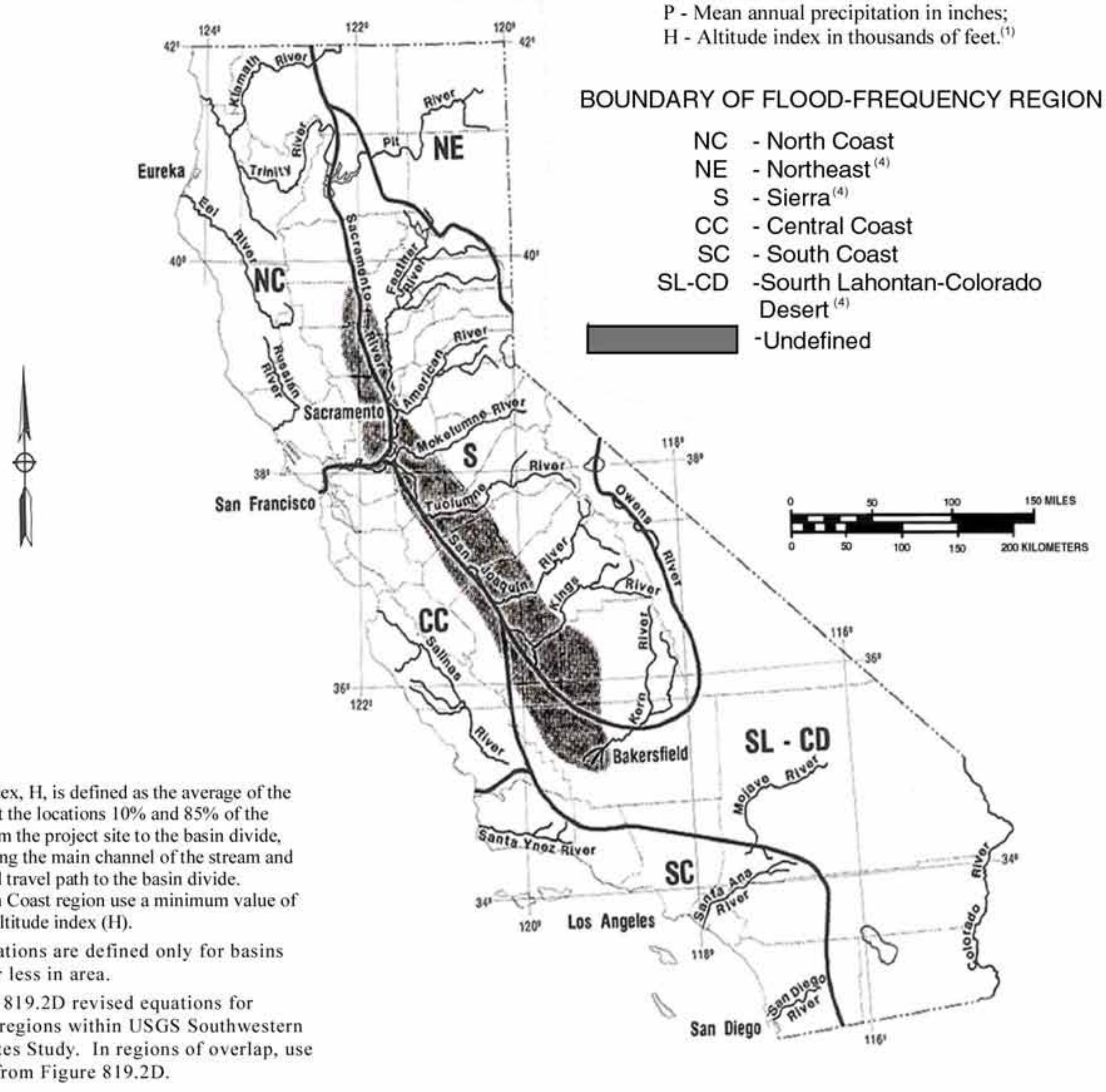
$Q_{10} = 0.63\ A^{0.79}\ p^{1.75}$

$Q_{25} = 1.10\ A^{0.81}\ p^{1.81}$

$Q_{50} = 1.50\ A^{0.82}\ p^{1.85}$

$Q_{100} = 1.95\ A^{0.83}\ p^{1.87}$

Q - Peak discharge in CFS, subscript indicates recurrence interval, in years;
A - Drainage area in square miles;
P - Mean annual precipitation in inches;
H - Altitude index in thousands of feet.(1)



Notes:

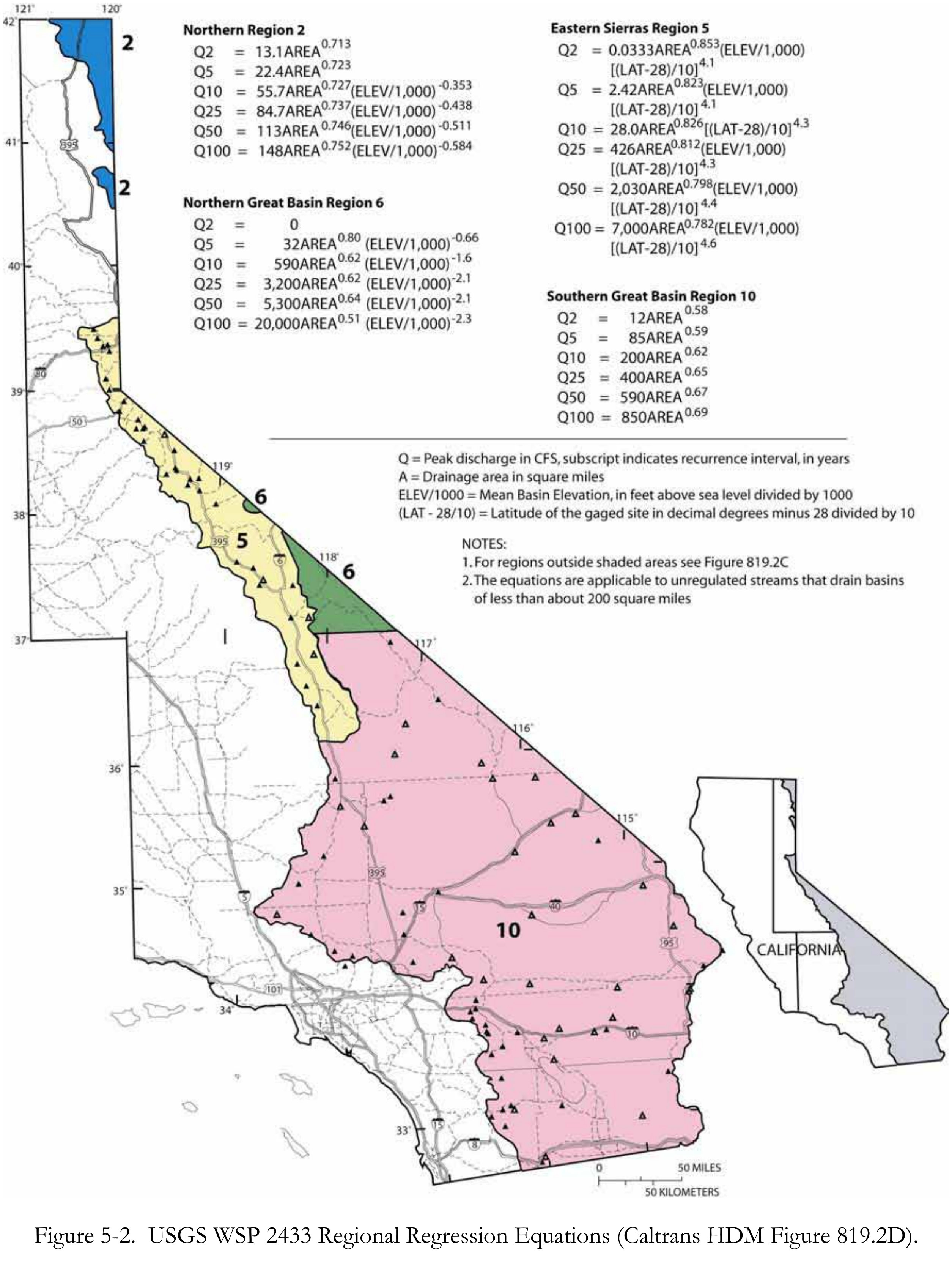
(1) Altitude index, H, is defined as the average of the elevations at the locations 10% and 85% of the distance from the project site to the basin divide, measure along the main channel of the stream and the overland travel path to the basin divide.

(2) In the North Coast region use a minimum value of 1.0 for the altitude index (H).

(3) These Equations are defined only for basins of 25mi² or less in area.

(4) See Figure 819.2D revised equations for California regions within USGS Southwestern United States Study. In regions of overlap, use equations from Figure 819.2D.

Figure 5-1. USGS WRI 77-21 Regional Regression Equations (Caltrans HDM Figure 819.2C).



Northern Region 2

$Q2 = 13.1\text{AREA}^{0.713}$

$Q5 = 22.4\text{AREA}^{0.723}$

$Q10 = 55.7\text{AREA}^{0.727}(\text{ELEV}/1{,}000)^{-0.353}$

$Q25 = 84.7\text{AREA}^{0.737}(\text{ELEV}/1{,}000)^{-0.438}$

$Q50 = 113\text{AREA}^{0.746}(\text{ELEV}/1{,}000)^{-0.511}$

$Q100 = 148\text{AREA}^{0.752}(\text{ELEV}/1{,}000)^{-0.584}$

Northern Great Basin Region 6

$Q2 = 0$

$Q5 = 32\text{AREA}^{0.80}(\text{ELEV}/1{,}000)^{-0.66}$

$Q10 = 590\text{AREA}^{0.62}(\text{ELEV}/1{,}000)^{-1.6}$

$Q25 = 3{,}200\text{AREA}^{0.62}(\text{ELEV}/1{,}000)^{-2.1}$

$Q50 = 5{,}300\text{AREA}^{0.64}(\text{ELEV}/1{,}000)^{-2.1}$

$Q100 = 20{,}000\text{AREA}^{0.51}(\text{ELEV}/1{,}000)^{-2.3}$

Eastern Sierras Region 5

$Q2 = 0.0333\text{AREA}^{0.853}(\text{ELEV}/1{,}000)[(\text{LAT}-28)/10]^{4.1}$

$Q5 = 2.42\text{AREA}^{0.823}(\text{ELEV}/1{,}000)[(\text{LAT}-28)/10]^{4.1}$

$Q10 = 28.0\text{AREA}^{0.826}[(\text{LAT}-28)/10]^{4.3}$

$Q25 = 426\text{AREA}^{0.812}(\text{ELEV}/1{,}000)[(\text{LAT}-28)/10]^{4.3}$

$Q50 = 2{,}030\text{AREA}^{0.798}(\text{ELEV}/1{,}000)[(\text{LAT}-28)/10]^{4.4}$

$Q100 = 7{,}000\text{AREA}^{0.782}(\text{ELEV}/1{,}000)[(\text{LAT}-28)/10]^{4.6}$

Southern Great Basin Region 10

$Q2 = 12\text{AREA}^{0.58}$

$Q5 = 85\text{AREA}^{0.59}$

$Q10 = 200\text{AREA}^{0.62}$

$Q25 = 400\text{AREA}^{0.65}$

$Q50 = 590\text{AREA}^{0.67}$

$Q100 = 850\text{AREA}^{0.69}$

Q = Peak discharge in CFS, subscript indicates recurrence interval, in years
A = Drainage area in square miles
ELEV/1000 = Mean Basin Elevation, in feet above sea level divided by 1000
(LAT - 28/10) = Latitude of the gaged site in decimal degrees minus 28 divided by 10

NOTES:
1. For regions outside shaded areas see Figure 819.2C
2. The equations are applicable to unregulated streams that drain basins of less than about 200 square miles

Figure 5-2. USGS WSP 2433 Regional Regression Equations (Caltrans HDM Figure 819.2D).

5.2 Applicability of Regression Equations

Comparisons of watershed characteristics between DWR detailed analysis units within each desert region and gaged watersheds that were used to develop regression equations were made to evaluate the representation of watershed conditions using the regression equations. Table 5-1 shows the mean annual precipitation and mean basin elevation for each of DWR detailed analysis units and each of the proposed desert regions.

Figure 5-3 through Figure 5-10 show the cloud values of the mean basin elevation and mean annual precipitation at gaging stations that were used to develop the regression equations in WSP 2433. For WSP 2433 Flood Region 10 that includes portions of the Colorado Desert, Sonoran Desert, Antelope Valley, Mojave Desert, and Owens Valley/Mono Lake desert regions, a large number of stations have a mean basin elevation higher than 3,500 ft and mean annual precipitation more than 10 inches (Figure 5-3 and Figure 5-4), which is not hydrologically similar to most arid basins in southern California. As shown in Table 5-1, the majority of basins in the Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert regions are at low elevations (generally lower than 3,500 ft) with low mean annual precipitation (generally less than 8 inches).

For WSP 2433 Flood Region 6 that covers a small portion of the Mojave Desert and Owens Valley/Mono Lake regions, the basin characteristics at many gaged basins that were used in WSP 2433 are not very similar to the basin characteristics in desert areas (Figure 5-5 and Figure 5-6). The mean annual precipitation at many stations is greater than 15 inches, which is higher than all DWR detailed analysis units in the Mojave Desert region and many stations in the Owens Valley/Mono Lake regions.

For WSP 2433 Flood Region 5 that includes a portion of the Owens Valley/Mono Lake region, the regression equations in WSP 2433 are even less representative of the flood relations in semi-arid areas where the mean annual precipitation is typically less than 20 inches (Figure 5-7 and Figure 5-8). More than 50 percent of the stations used to develop the regression equations have mean annual precipitation greater than 20 inches. These stations are generally on watersheds with high elevations which receive a significant amount of precipitation. A significant number of stations have a mean basin elevation above 8,000 ft, which is higher than most basins in the Owens Valley/Mono Lake region, making the regression equations less representative of the region.

Similarly, in WSP 2433 Flood Region 2 (Figure 5-9 and Figure 5-10), many stations used in WSP 2433 have the mean annual precipitation greater than 20 inches, which is not representative of watershed conditions in this semi-arid region. In WRI 77-21, the northeast region covers the entire Northern Basin and Range region. The regression equations in WRI 77-21 are also not very representative as the regression equations were only based on 18 stations with 8 stations having mean annual precipitation equal to or greater than 20 inches (Figure 5-11 and Figure 5-12). A significant number of stations have a mean basin elevation above 5,500 ft, which is higher than most basins in the Northern Basin and Range region, making the regression equations less representative.

Because of the significant differences between watershed characteristics of the stream-gaging stations used in the USGS regression equations and the characteristics of California's desert regions, the current regression equations in WSP 2433 and WRI 77-21 are not recommended as the primary approach for estimating flood-frequency flows for design of bridges and culverts. However, they still provide valuable means to compare discharges estimated using a rainfall-runoff approach.

Table 5-1. Basin Mean Precipitation and Elevation for Each DWR Detailed Analysis Unit (DAU) and Desert Region.

DAU_CODE	Region	Precipitation (inches)	Percent of Average Region Precipitation (%)	Mean Basin Elevation (ft)	Percent of Average Region Elevation (%)
353	Region 1 - Colorado Desert	2.8	50	218	17
351	Region 1 - Colorado Desert	3.1	56	232	18
356	Region 1 - Colorado Desert	3.2	58	623	49
349	Region 1 - Colorado Desert	4.3	78	1503	119
354	Region 1 - Colorado Desert	5.4	97	1373	109
350	Region 1 - Colorado Desert	6.3	113	2587	205
355	Region 1 - Colorado Desert	7.1	128	1964	156
352	Region 1 - Colorado Desert	7.3	132	1899	150
348	Region 1 - Colorado Desert	8.9	161	2369	188
AVERAGES	Region 1 - Colorado Desert	5.4		1339	
338	Region 2 - Sonoran Desert	3.5	81	2011	198
335	Region 2 - Sonoran Desert	3.8	88	1295	128
347	Region 2 - Sonoran Desert	3.8	89	474	47
334	Region 2 - Sonoran Desert	3.9	90	1011	100
345	Region 2 - Sonoran Desert	4.2	96	573	56
346	Region 2 - Sonoran Desert	4.4	101	1008	99
333	Region 2 - Sonoran Desert	4.4	103	1102	109
344	Region 2 - Sonoran Desert	5.0	116	831	82
342	Region 2 - Sonoran Desert	5.2	120	876	86
343	Region 2 - Sonoran Desert	5.7	132	1216	120
AVERAGES	Region 2 - Sonoran Desert	4.3		1015	
306	Region 3 - Antelope Valley	6.2	74	2605	82
304	Region 3 - Antelope Valley	7.5	90	3387	107
308	Region 3 - Antelope Valley	7.9	95	3615	114
305	Region 3 - Antelope Valley	11.3	135	3409	108
307	Region 3 - Antelope Valley	11.7	140	3772	119
AVERAGES	Region 3 - Antelope Valley	8.4		3168	
331	Region 4 - Mojave Desert	3.2	61	1352	49
328	Region 4 - Mojave Desert	3.3	63	1706	62
287	Region 4 - Mojave Desert	3.5	67	3443	124
325	Region 4 - Mojave Desert	3.6	70	2647	96
284	Region 4 - Mojave Desert	3.7	70	5084	184
327	Region 4 - Mojave Desert	3.7	72	2229	81
318	Region 4 - Mojave Desert	3.8	73	2043	74
296	Region 4 - Mojave Desert	3.8	74	3420	124
288	Region 4 - Mojave Desert	4.0	76	2808	102
336	Region 4 - Mojave Desert	4.0	77	2407	87
285	Region 4 - Mojave Desert	4.1	78	2427	88
300	Region 4 - Mojave Desert	4.1	79	3120	113
299	Region 4 - Mojave Desert	4.1	79	2710	98
324	Region 4 - Mojave Desert	4.2	80	2649	96
311	Region 4 - Mojave Desert	4.3	82	2659	96
312	Region 4 - Mojave Desert	4.3	83	2514	91
316	Region 4 - Mojave Desert	4.4	83	2113	76
313	Region 4 - Mojave Desert	4.4	84	2029	73
314	Region 4 - Mojave Desert	4.4	85	2736	99
322	Region 4 - Mojave Desert	4.4	85	3112	113
297	Region 4 - Mojave Desert	4.5	85	3405	123
294	Region 4 - Mojave Desert	4.5	86	3469	125
293	Region 4 - Mojave Desert	4.5	86	3034	110
295	Region 4 - Mojave Desert	4.5	86	3197	116
315	Region 4 - Mojave Desert	4.5	86	2546	92
292	Region 4 - Mojave Desert	4.5	86	2727	99
310	Region 4 - Mojave Desert	4.8	92	2934	106
289	Region 4 - Mojave Desert	5.0	96	2981	108
286	Region 4 - Mojave Desert	5.3	101	2937	106
332	Region 4 - Mojave Desert	5.4	103	1709	62
298	Region 4 - Mojave Desert	5.5	106	3799	137
317	Region 4 - Mojave Desert	5.6	106	3150	114
329	Region 4 - Mojave Desert	5.8	110	2973	107
290	Region 4 - Mojave Desert	5.8	110	3271	118
340	Region 4 - Mojave Desert	6.0	114	1419	51
323	Region 4 - Mojave Desert	6.4	122	3601	130
341	Region 4 - Mojave Desert	6.6	126	1485	54
339	Region 4 - Mojave Desert	6.9	131	2638	95
326	Region 4 - Mojave Desert	6.9	132	3756	136
291	Region 4 - Mojave Desert	7.3	140	3682	133
321	Region 4 - Mojave Desert	7.5	143	3451	125
283	Region 4 - Mojave Desert	7.8	150	4414	160
337	Region 4 - Mojave Desert	7.9	150	4028	146
320	Region 4 - Mojave Desert	7.9	151	4063	147
330	Region 4 - Mojave Desert	8.1	155	4270	154
319	Region 4 - Mojave Desert	8.5	162	3791	137
309	Region 4 - Mojave Desert	12.0	230	3707	134
AVERAGES	Region 4 - Mojave Desert	5.2		2766	

Table 5-1 (cont'd). Basin Mean Precipitation and Elevation for Each DWR Detailed Analysis Unit (DAU) and Desert Region.

DAU_CODE	Region	Precipitation (inches)	Percent of Average Region Precipitation (%)	Mean Basin Elevation (ft)	Percent of Average Region Elevation (%)
301	Region 5 - Owens Valley/Mono Lake	4.6	39	4558	74
302	Region 5 - Owens Valley/Mono Lake	4.9	42	5435	88
303	Region 5 - Owens Valley/Mono Lake	6.4	54	3674	60
279	Region 5 - Owens Valley/Mono Lake	6.6	56	5661	92
282	Region 5 - Owens Valley/Mono Lake	8.6	73	5227	85
275	Region 5 - Owens Valley/Mono Lake	10.8	92	7461	121
278	Region 5 - Owens Valley/Mono Lake	11.5	97	5844	95
277	Region 5 - Owens Valley/Mono Lake	12.9	110	7022	114
281	Region 5 - Owens Valley/Mono Lake	13.4	114	7305	119
280	Region 5 - Owens Valley/Mono Lake	17.6	150	7839	127
274	Region 5 - Owens Valley/Mono Lake	18.3	155	7758	126
276	Region 5 - Owens Valley/Mono Lake	19.5	166	8218	133
AVERAGES	Region 5 - Owens Valley/Mono Lake	11.8		6164	

263	Region 6 - Northern Basin and Range	11.2	71	5743	108
265	Region 6 - Northern Basin and Range	11.4	72	4817	90
262	Region 6 - Northern Basin and Range	13.8	87	5376	101
130	Region 6 - Northern Basin and Range	17.1	108	5321	100
266	Region 6 - Northern Basin and Range	18.3	115	5464	103
264	Region 6 - Northern Basin and Range	20.4	128	4966	93
AVERAGES	Region 6 - Northern Basin and Range	15.9		5331	

Note: For the Colorado Desert region, DAU 357 was not included because it represents the Salton Sea.

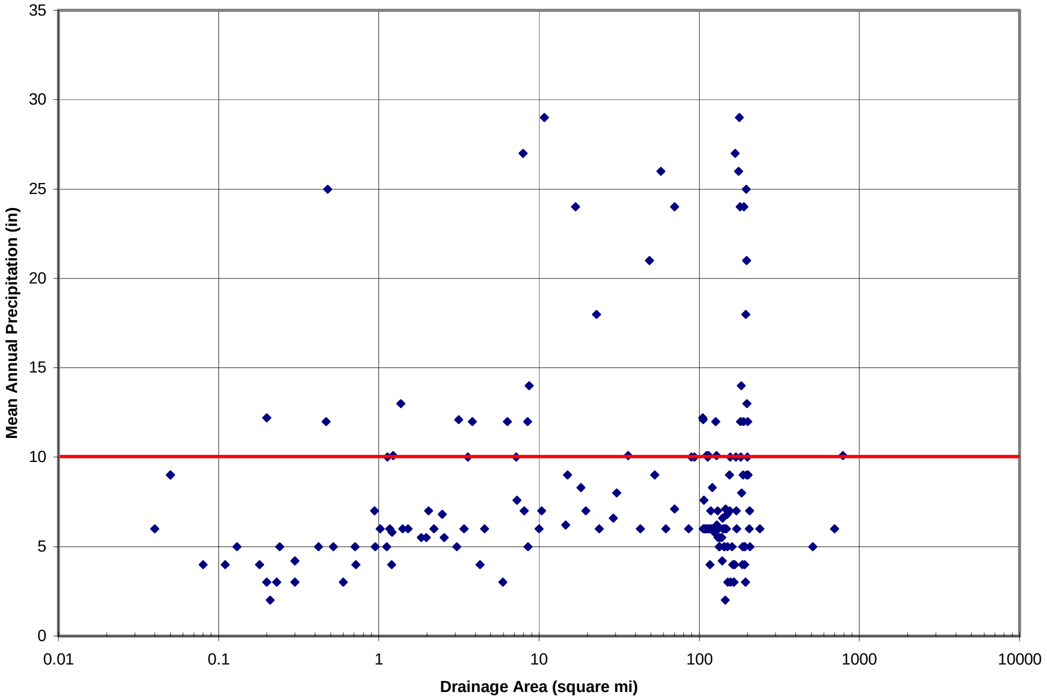


Figure 5-3. Cloud Values of Mean Annual Precipitation in WSP 2433 Region 10.

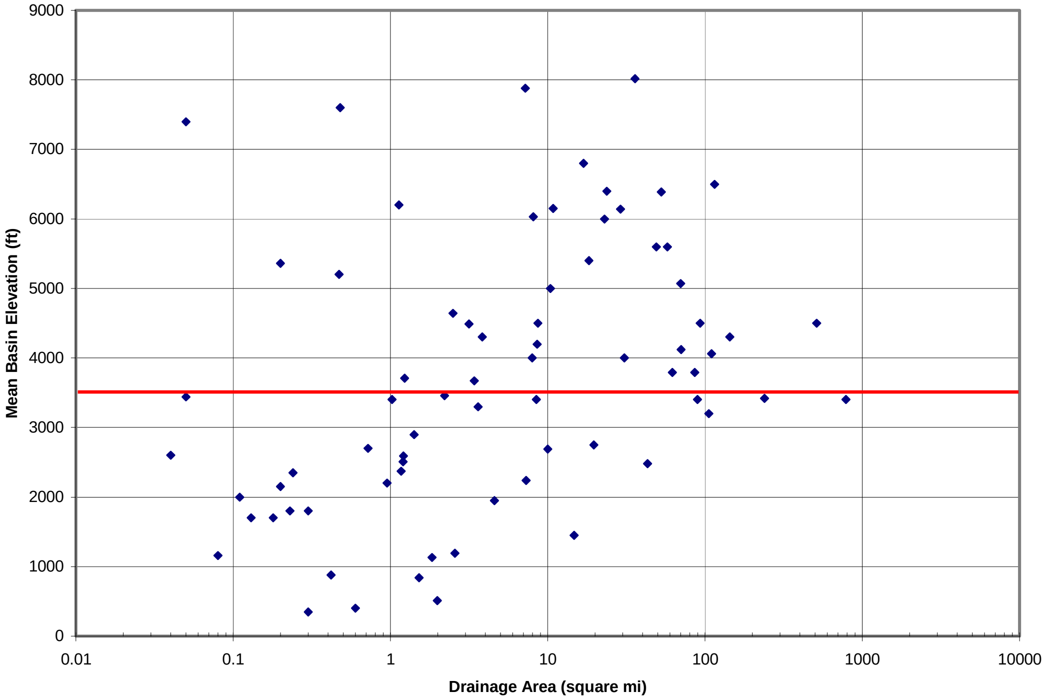


Figure 5-4. Cloud Values of Mean Basin Elevation in WSP 2433 Region 10.

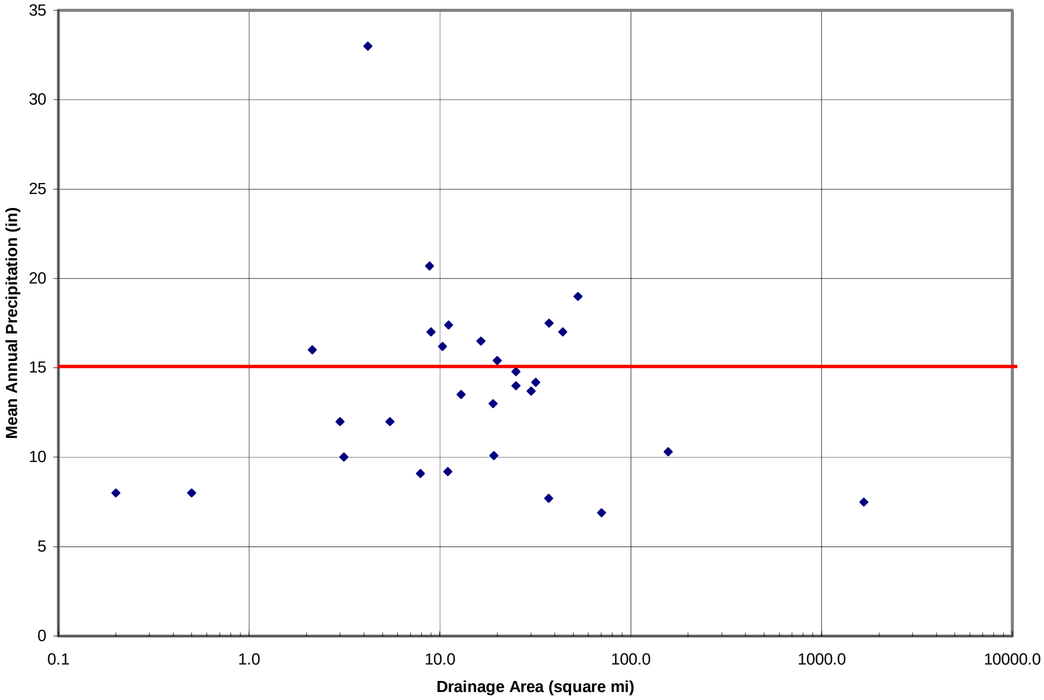


Figure 5-5. Cloud Values of Mean Annual Precipitation in WSP 2433 Region 6.

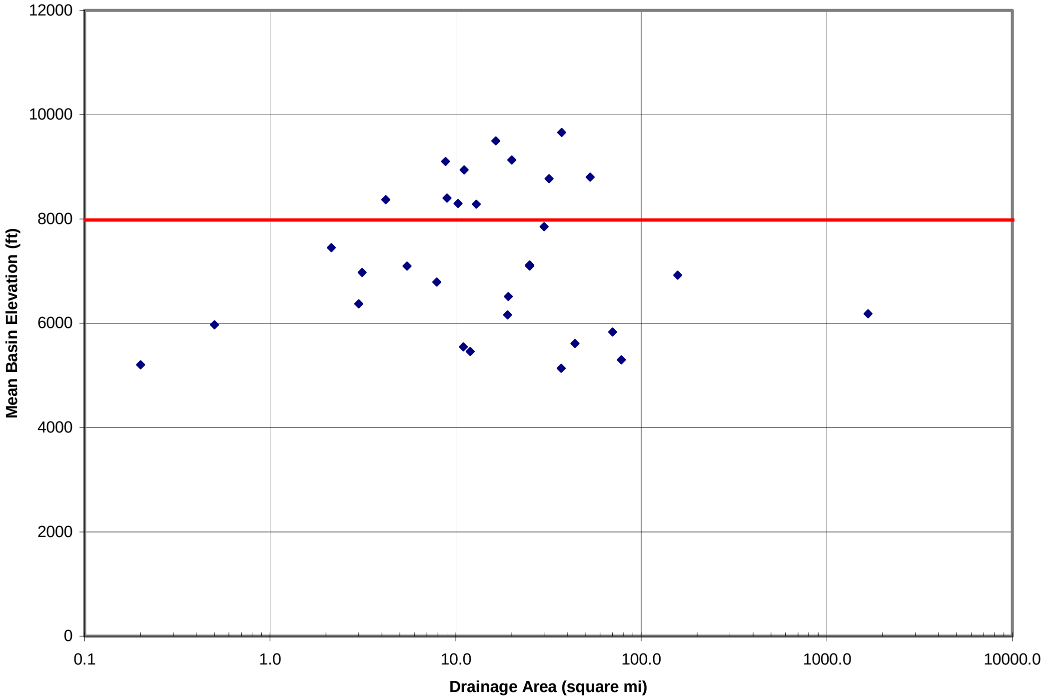


Figure 5-6. Cloud Values of Mean Basin Elevation in WSP 2433 Region 6.

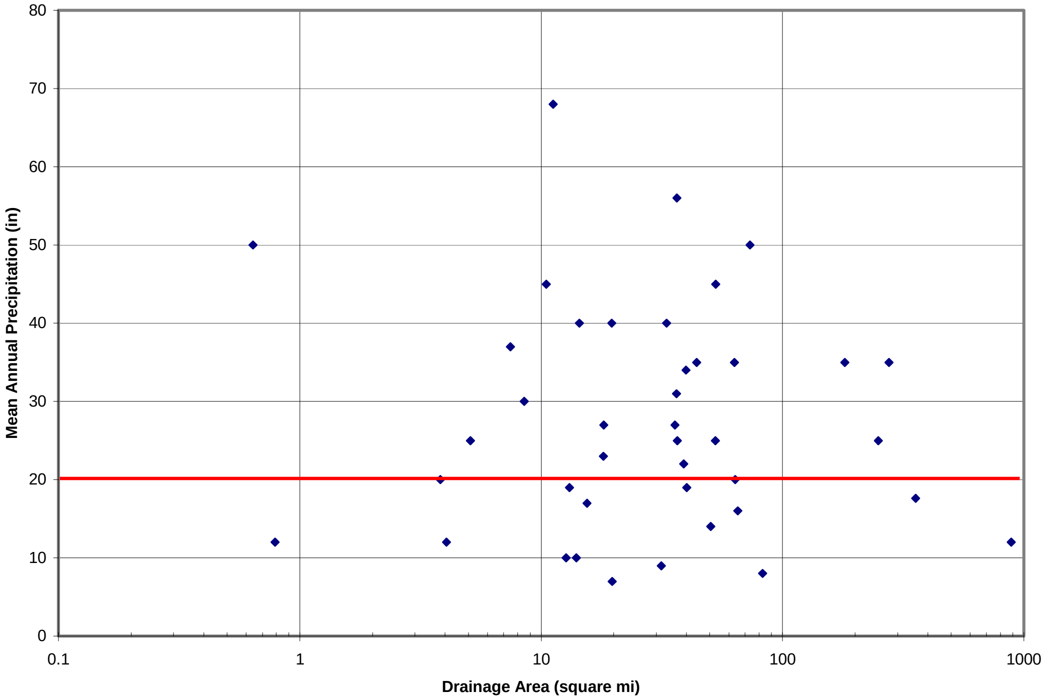


Figure 5-7. Cloud Values of Mean Annual Precipitation in WSP 2433 Region 5.

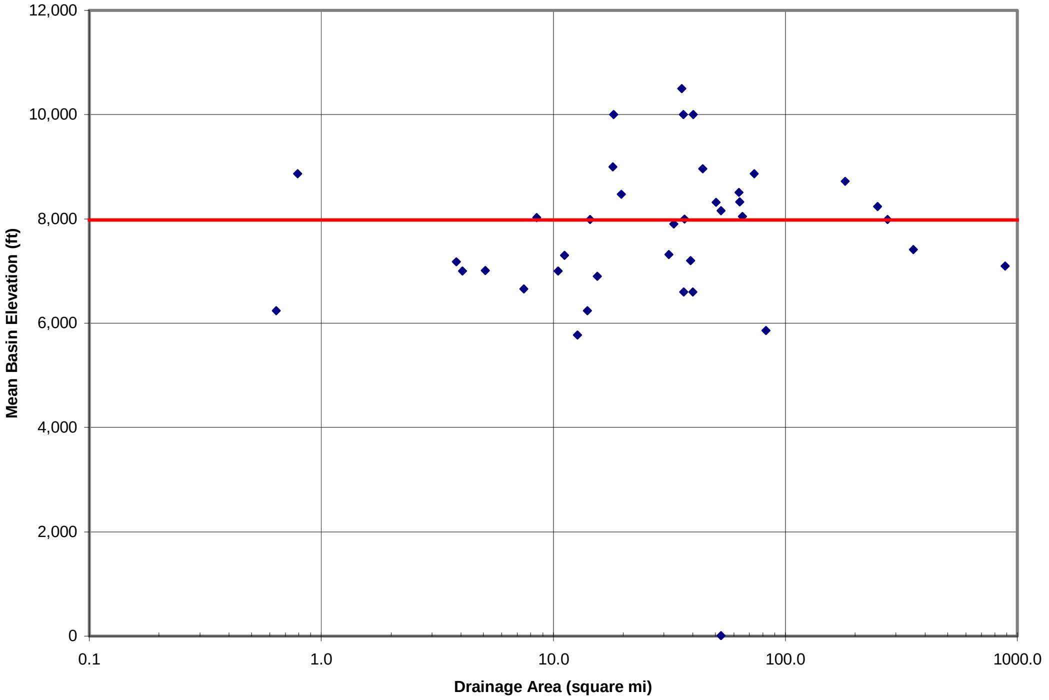


Figure 5-8. Cloud Values of Mean Basin Elevation in WSP 2433 Region 5.

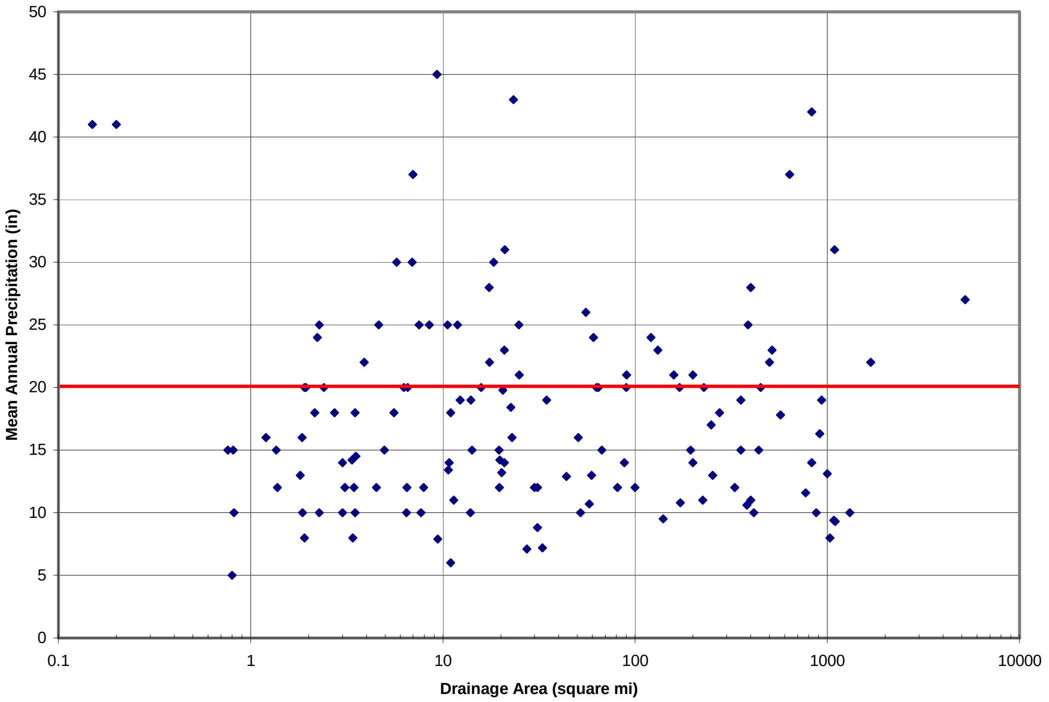


Figure 5-9. Cloud Values of Mean Annual Precipitation in WSP 2433 Region 2.

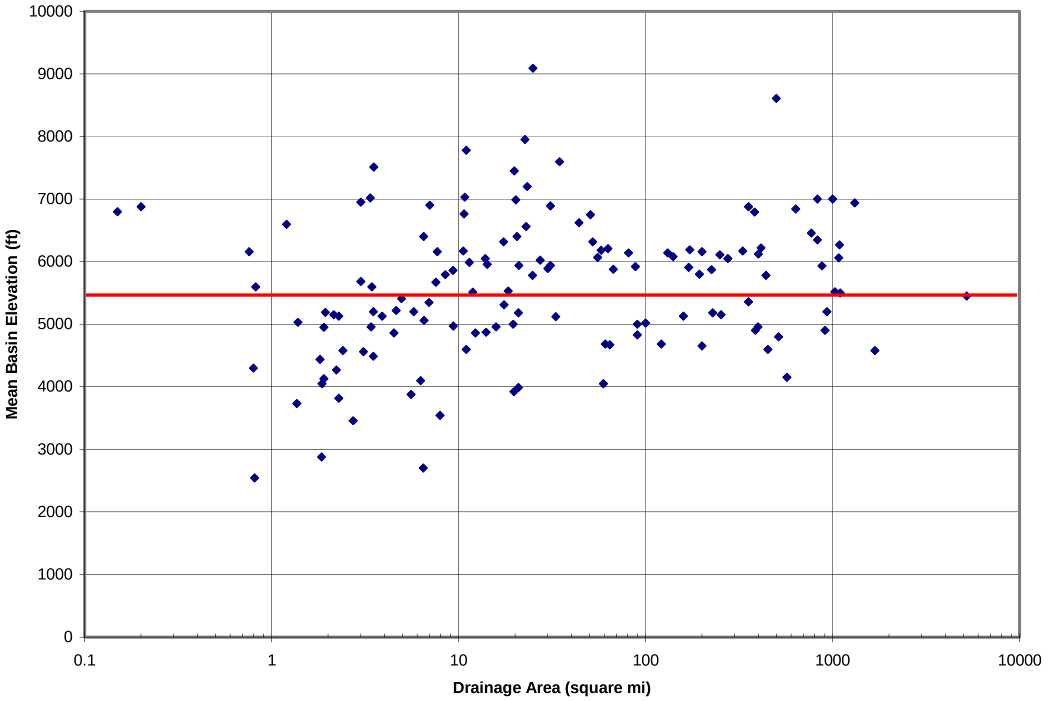


Figure 5-10. Cloud Values of Mean Basin Elevation in WSP 2433 Region 2.

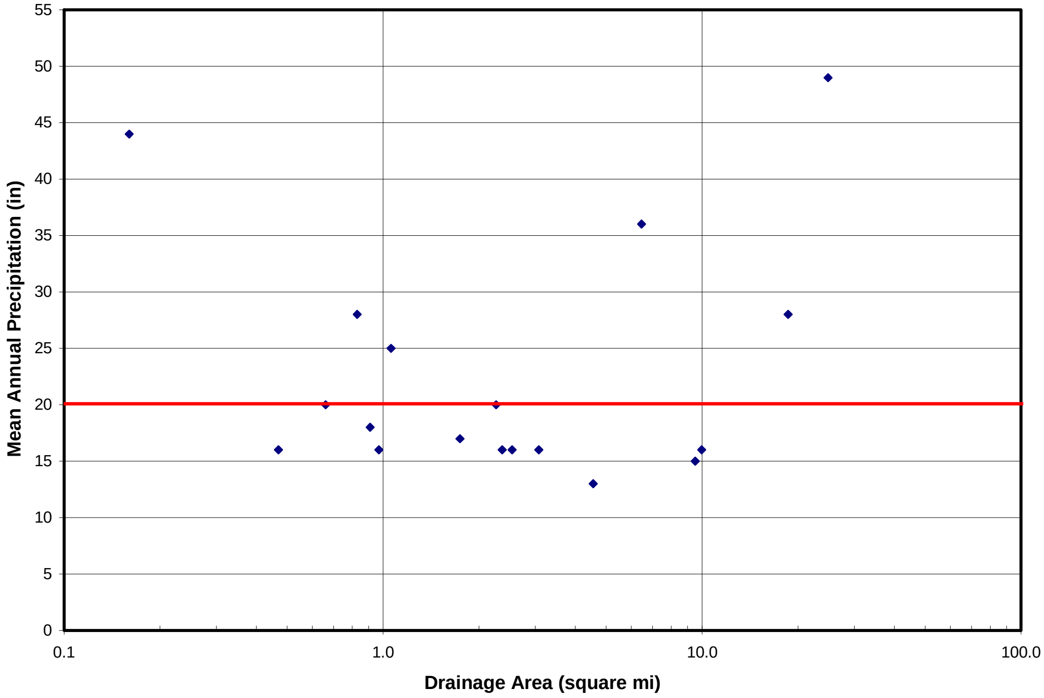


Figure 5-11. Cloud Values of Mean Annual Precipitation in WRI 77-21 Northeast Region.

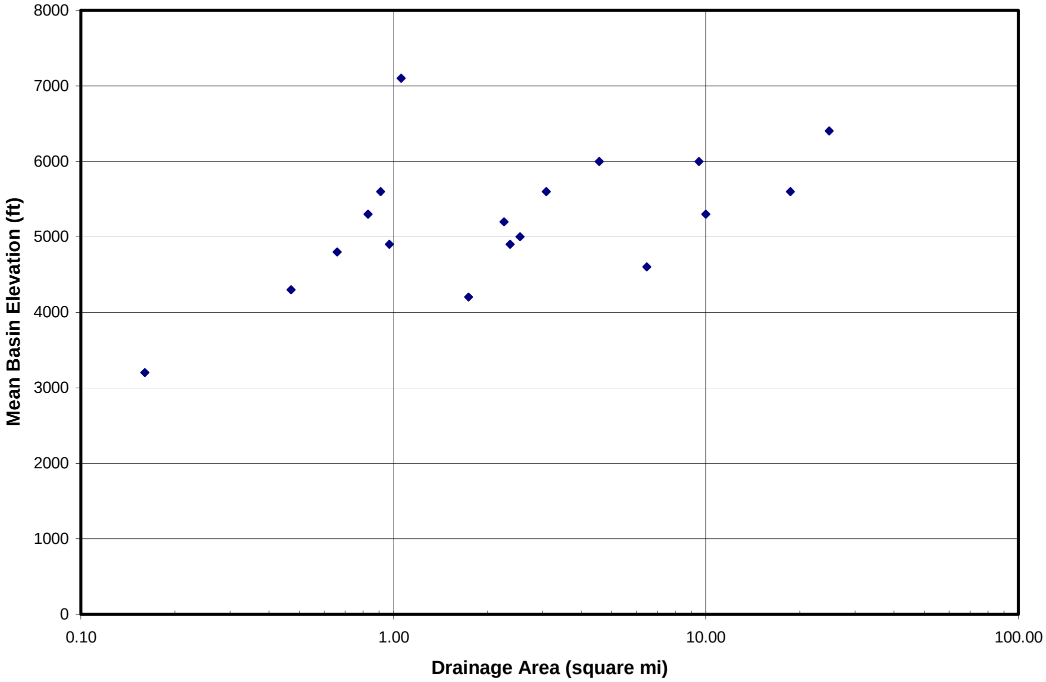


Figure 5-12. Cloud Values of Mean Basin Elevation in WRI 77-21 Northeast Region.

5.3 Study Approach

The current regional regression equations in WSP 2433 and WRI 77-21 are considered not representative of the watershed conditions in our desert study area. However, the data set that was used to develop the regression equations can be reduced to a subset such that all selected stations have watershed characteristics similar to California's desert regions. New regression equations can then be developed from the reduced data set. Such revised equations should be much more representative of desert flood conditions. They may also provide good data to check the reasonableness of peak discharges computed using rainfall-runoff simulation for an ungaged watershed. The development of new regional regression equations is described in Chapter 6.

6 REGIONAL REGRESSION: REVISED EQUATIONS

Three new sets of regional regression equations were developed based on a subset of data from WSP 2433 and WRI 77-21 that corresponds better to California's desert regions.

One set of regional regression equations was developed for the southern desert regions (Colorado Desert, Sonoran Desert, Mojave Desert, and the Antelope Valley). A hybrid regional regression analysis, the same approach used in WSP 2433 for Region 10, was conducted to develop new regression equations. Using standard regression analyses, a new set of regional regression equations was developed for the Owens Valley/Mono Lake region using a subset of data from WSP 2433 Regions 5 and 6. For the Northern Basin and Range, a combination of data from WSP 2433 Region 2 and WRI 77-21 Northeast Region was used to develop new regression equations.

6.1 Southern Desert Regions

As typically observed in arid areas, California's southern desert regions (Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert) share the following characteristics:

- The majority of basins in the regions have low mean annual precipitation.
- Long periods of streamflow records are typically not available for most basins.
- The streamflow records at many gaging stations have many years of zero flow due to the nature of intermittent or ephemeral streams.
- Summer thunderstorms often occur over small and isolated basins. Flood events from these thunderstorms are often unrepresented by the few gages that do have a long flow record.
- The flood-frequency relations developed for gages with a limited period of record often have significant variability that cannot be reliably fitted with a theoretical distribution, such as the log-Pearson Type III distribution typically used with peak streamflow data.

Because of these characteristics, a conventional regression analysis, which typically requires flood-frequency discharges at stations with at least 10 years of annual peaks (and without multiple years of zero flow) to develop a regression equation, is generally inadequate for these arid regions. As a result, in WSP 2433 a hybrid analysis was used which combines elements of the station-year method and multiple-regression analysis. Individual flood-frequency relations developed using a flood-frequency analysis at gaged sites are not used in the hybrid method. Instead, all annual peaks from all gaging stations that had at least 10 years of record were combined into one composite data set. In this study, a similar hybrid regression analysis was performed using a subset of the data that better represents the watershed conditions in California's southern desert regions.

It should be noted that a few gages in the southern desert regions have a long enough period of record (20 or more years) and few enough zero flow years to allow for reasonable flood-frequency relationships to be developed at those gages. While these gages are not enough to produce a reasonable regional regression equation for the southern desert regions – hence the need for the hybrid regression method – they can be used for comparison with the hybrid regression results.

6.1.1 Hybrid Regression Method

The hybrid method for a regional regression analysis is described in detail by Hjalmarson and Thomas (1992). It combines all annual peaks recorded at gaging stations and historic flood estimates at ungaged sites within a hydrologically similar region into a single long record, assuming that the peaks are independent between stations. The hybrid method uses the following regression equation, which is commonly used in regional flood-frequency analyses:

$$Q_t = aA^b B^c C^d \tag{6.1}$$

where Q_t is the discharge for the t-year recurrence interval; a is a coefficient; A, B, C are independent basin and climatic parameters; and b, c, d are regression exponents.

Because drainage area is the most significant independent variable that affects flood characteristics, the hybrid method starts the regression between discharge and drainage area. It involves the following steps:

Step 1. The drainage area for all sites is ranked from the smallest to the largest. The combined single long record is then divided into three or more groups according to basin drainage area. Each group has a number of stations (see Figure 6-1 for an illustration). Each station has a number of years with flow or with zero flow. To ensure an unbiased relation in the regression analysis, each group has a nearly equal sample size.

Step 2. Each peak discharge within each group is standardized by dividing by A^b (the exponent b is equal to one for the first iteration) where A is the drainage area.

Step 3. In each group, the exceedance probabilities of the standardized peaks can be estimated either by fitting a theoretical flood-frequency curve if appropriate or simply by using a plotting-position formula. To avoid extrapolations to the 100-year flood level, each group has at least 100 station-years (peaks) with flow to estimate the 0.01 probability discharge. If an elementary plotting-position formula is used, a theoretical probability distribution is no longer required. This advantage is important because in semi-arid and arid regions, many station flood-frequency relations are typically undefined or unreliable if fitted with a theoretical curve. In this study, the probabilities are simply computed using the Cunnane plotting-position formula (Cunnane, 1978). The Cunnane formula was used because it is an unbiased and relatively distribution-free plotting position, implying that it is appropriate when the underlying distribution of the data is not known (Cunnane, 1978). A linear interpolation in log-probability space is necessary to obtain frequency flows for the t-year discharges.

Step 4. The frequency flows for each group obtained in Step 3 are de-standardized by multiplying by the weighted geometric mean drainage area.

Step 5. For each recurrence interval, a linear regression analysis is conducted between Q_t and mean drainage area in log space (see Figure 6-1 for a sample regression line), and a new exponent, b, is computed. To perform a linear regression, the combined data set has to be divided into at least three groups.

Step 6. Using the new exponent, an iterative process that uses a regression and flood-frequency analysis is repeated until the computations converge on the exponent value.

Each additional parameter can be separately added to the relation with the same iterative technique starting at Step 1. The new parameter is used in place of drainage area. The original peak discharges are replaced with standardized discharges obtained from the last iteration with the previous parameter. The coefficient *a* in Equation 6.1 is determined during the last linear regression (in log space) of the last parameter.

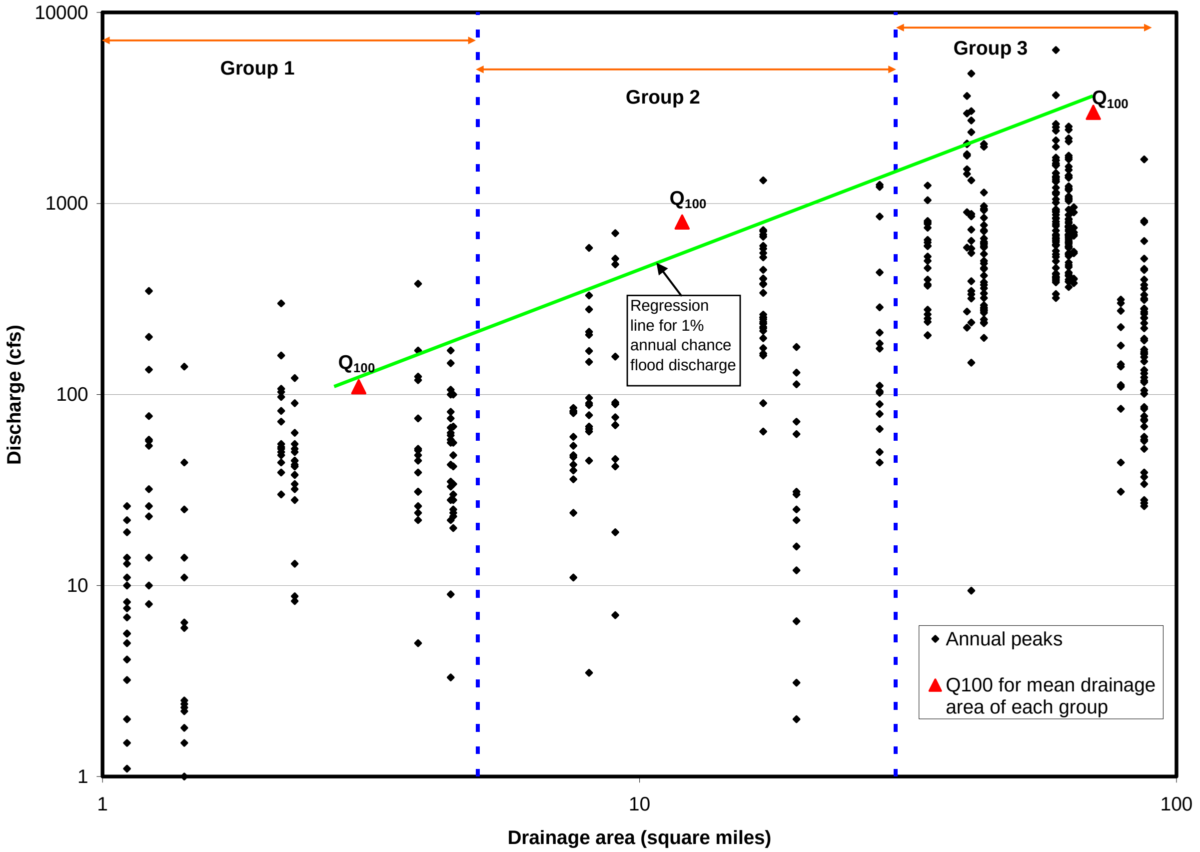


Figure 6-1. Sample Regression Relation for Base Flood Discharges using the Hybrid Method.

6.1.2 Data Set

All gaging stations used in WSP 2433 and located within the Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert regions were first identified. To form a subset of stations with watershed characteristics more representative of flood conditions in these desert areas (see Table 5-1), all stations with the mean annual precipitation greater than 15 inches and the mean basin elevation greater than 4,500 feet were not used. There are a total of 52 stations in the new data set. Table 6-1 summarizes the stations and their watershed characteristics. Appendix C includes their geographic locations.

Peak discharges used in the analysis were recorded as being unaffected by regulation, diversion, dam failure, canal operation, or urbanization.

Table 6-1. Summary of Streamflow Stations Used in Hybrid Regression Analysis.

ID	USGS Station #	Station Name	Latitude (Deg, Min, Sec)	Longitude (Deg, Min, Sec)	Drainage Area (sq mi)	Beginning of Peak Flow data	End of Peak Flow Data	Years of Record	Elevation at Gaging Station
Region 1 - Colorado Desert									
S101	10254020	BETZ WASH NR SALTON BEACH CA	33 29 53	115 54 16	5.95	1960	10/18/1972	14	
S103	10254475	GLAMIS WASH A GLAMIS CA	32 59 53	115 04 10	0.60	12/25/1959	11/16/1973	15	340' Above Sea Level NGVD29
S107	10255200	MYER C TRIB NR JACUMBA CA	32 40 25	116 04 50	0.11	9/1/1960	8/20/1973	14	1,880' Above Sea Level NGVD29
S108	10255230	MYER C TRIB NO 2 NR COYOTE WELLS CA	32 43 14	116 02 40	0.08	9/1/1960	8/20/1973	14	820' Above Sea Level NGVD29
S111	10255700	SAN FELIPE C NR JULIAN CA	33 07 07	116 26 04	89.20	2/16/1959	3/1/1983	25	
S112	10255730	PINYON WASH NR BORREGO CA	33 06 55	116 19 00	19.60	1960	1973	14	1,400' Above Sea Level NGVD29
S113	10255800	COYOTE C NR BORREGO SPRINGS CA	33 22 25	116 25 36	144.00	7/28/1951	2/15/1986	36	1,200' Above Sea Level NGVD29
S116	10255820	YAQUI PASS WASH NR BORREGO CA	33 08 50	116 21 00	0.04	8/31/1960	1973	14	1,720' Above Sea Level NGVD29
S117	10255825	YAQUI PASS WASH NO 2 NR BORREGO CA	33 09 05	116 20 55	0.03	8/31/1960	3/9/1973	14	1,680' Above Sea Level NGVD29
S118	10255850	VALLECITO C NR JULIAN CA	32 59 10	116 25 10	39.70	7/31/1964	8/15/1983	20	1,860' Above Sea Level NGVD29
S119	10255885	SAN FELIPE C NR WESTMORLAND CA	33 07 26	115 51 08	1693.00	8/29/1961	8/26/1988	28	-180' Above Sea Level NGVD29
S124	10256400	SAN GORGONIO R NR WHITE WATER CA	33 55 08	116 41 52	154.00	11/23/1965	1/5/1979	14	1,320' Above Sea Level NGVD29
S130	10257600	MISSION C NR DESERT HOT SPRINGS CA	34 00 40	116 37 38	35.60	7/28/1968	1/11/2005	37	
S136	10258500	PALM CYN C NR PALM SPRINGS CA	33 44 42	116 32 05	93.10	8/1/1930	1/9/2005	71	700' Above Sea Level NGVD29
S137	10259000	ANDREAS C NR PALM SPRINGS CA	33 45 36	116 32 57	8.65	4/18/1949	12/25/2003	56	800' Above Sea Level NGVD29
S140	10259200	DEEP C NR PALM DESERT CA	33 37 52	116 23 29	30.60	1962	12/29/2004	44	1,440' Above Sea Level NGVD29
S141	10259300	WHITEWATER R A INDIO CA	33 44 14	116 14 07	1073.00	11/22/1965	1/11/2005	37	
S142	10259500	THERMAL CYN TRIB NR MECCA	33 40 50	115 59 25	0.18	1960	8/3/1973	14	1,640' Above Sea Level NGVD29
S144	10259600	COTTONWOOD WASH NR COTTONWOOD SPRINGS CA	33 44 40	115 49 35	0.65	9/5/1960	10/3/1972	14	3,080' Above Sea Level NGVD29
Region 2 - Sonoran Desert									
S200	9428530	ARCH C NR EARP CA	34 09 55	114 22 20	1.52	21806	10/3/1972	15	600' NGVD29
S201	9428560	COLORADO R TRIB NO 2 NR VIDAL CA	33 59 11	114 29 45	0.39	9/1/1960	10/3/1972	14	350' NGVD29
S202	9428570	COLORADO R TRIB NR VIDAL CA	33 58 47	114 30 23	1.12	9/1/1960	5/26/1905	14	380' NGVD29
S205	9429240	OGILBY WASH NR PALO VERDE CA	33 20 20	114 46 45	0.05	12/25/1959	10/6/1972	14	
S206	9429250	OGILBY WASH NO 2 NR PALO VERDE CA	33 20 25	114 46 45	0.02	12/25/1959	10/6/1972	14	
S217	10253700	PALEN DRY LK TRIB NR DESERT CENTER CA	33 41 45	115 28 45	0.04	9/6/1960	1/18/1973	14	
S218	10253750	MONUMENT WASH NR DESERT CENTER CA	33 42 30	115 21 50	4.29	7/22/1960	1/18/1973	14	
S219	10253800	COXCOMB WASH NR DESERT CENTER CA	33 48 25	115 17 10	0.03	3/24/1960	10/9/1972	14	
Region 3 - Antelope Valley									
S312	10264520	AMARGOSA C TRIB NR LEONA VALLEY CA	34 37 51	118 19 32	0.05	2/11/1959	12/16/1988	16	
S313	10264530	PINE C NR PALMDALE CA	34 36 09	118 14 48	1.78	1/6/1959	12/29/2004	42	
S316	10264560	SPENCER CYN C NR FAIRMONT CA	34 46 32	118 34 06	3.60	1/6/1959	1/10/2005	43	2,940' Above Sea Level NGVD29
S319	10264605	JOSHUA C NR MOJAVE CA	35 00 45	118 20 40	3.83	1/6/1959		21	3,800' Above Sea Level NGVD29
S331	10264700	PEEWEE C NR RANDSBURG CA	35 27 40	117 39 20	0.14	1967	5/14/1973	15	
S334	10264750	PINE TREE C NR MOJAVE CA	35 13 50	118 05 07	34.16	7/30/1959	1/16/1979	20	2,720' Above Sea Level NGVD29
Region 4 - Mojave Desert									
S400	9423400	TIN CAN C NR NEEDLES CA	34 51 25	114 52 55	0.04	11/11/1958	2/21/1973	15	
S401	9424050	CHEMEHUEVI WASH TRIB NR NEEDLES CA	34 30 30	114 36 10	2.04	12/25/1959	11/14/1972	14	1,600' Above Sea Level NGVD29
S405	10250720	ONYX C NR BALLARAT CA	36 01 20	117 18 45	0.52	9/20/1963	5/26/1905	11	
S408	10251000	BIG DIP C NR STOVEPIPE WELLS CA	36 55 05	117 17 35	0.95	11/11/1958	10/20/1972	15	
S410	10251200	SPRING C A FURNACE C INN CA	36 26 40	116 50 15	0.21	9/12/1959	2/11/1973	15	
S413	10251300	AMARGOSA RIVER AT TECOPA, CA	35 50 55	116 13 45	3090.00	9/26/1962	2/22/2005	30	1,310' Above Sea Level NGVD29
S416	10251400	IBEX C NR TECOPA CA	35 47 15	116 20 00	0.20	9/13/1959	10/3/1972	15	
S417	10251500	YUCCA C NR YUCCA GROVE CA	35 24 30	115 46 20	0.03	8/7/1959	2/28/1973	15	
S418	10251600	SALSBERRY C NR SHOSHONE CA	35 55 10	116 26 05		5/12/1905	10/3/1972	15	
S419	10252300	CHINA SPRING C NR MOUNTAIN PASS CA	35 28 05	115 30 30	0.94	5/12/1905	5/26/1905	15	
S422	10253000	GOURD C NR LUDLOW CA	34 40 35	116 01 20	0.34	5/12/1905	12/29/2004	37	1,720' Above Sea Level NGVD29
S424	10253250	GRANITE WASH NR RICE CA	34 02 50	115 13 05		1/12/1960	5/26/1905	14	
S425	10253255	GRANITE WASH NO 2 NR RICE CA	34 02 55	115 13 00	0.01	1/12/1960	5/26/1905	14	
S427	10253350	FORTYNINE PALMS C NR TWENTYNINE PALMS CA	34 07 12	116 05 43	8.55	5/14/1905	7/20/1979	18	2,315' Above Sea Level NGVD29
S428	10260200	PIPES C NR YUCCA VALLEY CA	34 10 19	116 32 45	15.10	5/12/1905	7/20/1979	21	4,440' Above Sea Level NGVD29
S429	10260400	CUSHENBURY C NR LUCERNE CA	34 21 52	116 50 42	6.36	4/11/1958	7/20/1979	20	
S442	10261800	BEACON C A HELENDALE CA	34 45 00	117 18 53	0.72	9/13/1959	6/19/1905	27	2,450' Above Sea Level NGVD29
S446	10262600	BOOM C NR BARSTOW CA	34 54 20	116 56 55	0.24	9/13/1959	10/20/2004	40	2,270' Above Sea Level NGVD29
S448	10263100	ZZYZX C NR BAKER CA	35 11 40	116 09 05	0.23	5/12/1905	5/22/1905	11	

6.1.3 Hybrid Regression Results

Because WSP 2433 had included extensive sensitivity tests to examine the best correlation between the dependent variable (the peak discharge) and independent variables (i.e., the drainage area, mean basin elevation, etc.), the same formulations as those in WSP 2433 were adopted in this study. For Region 10 of WSP 2433, the flood-frequency discharges are a function of the drainage area only.

Because WSP 2433 only used annual peaks through Water Year 1986, the hybrid regression analysis was first conducted using annual peaks through Water Year 1986. In the analysis, the only parameter that needs to be specified is the number of groups. This was determined using a sensitivity analysis by comparing the frequency discharges from the hybrid regression analysis and the log-Pearson Type III flood-frequency analysis included in WSP 2433. To increase the reliability of the log-Pearson Type III flood-frequency analysis, only stations with at least 20 years of record (through Water Year 1986) and with the log-Pearson Type III flood frequency flows analyzed and reported in WSP 2433 were selected (see Table 6-2).

Table 6-2. List of Selected Streamflow Stations for Comparing Hybrid Regression Results.

ID	Station #	Station Name	Latitude (Deg, Min, Sec)	Longitude (Deg, Min, Sec)	Drainage Area (sq mi)	Beginning of Peak Flow data	End of Peak Flow Data	Years of Record
Region 1 - Colorado Desert								
S111	10255700	SAN FELIPE C NR JULIAN CA	33 07 07	116 26 04	89.20	2/16/1959	3/1/1983	25
S113	10255800	COYOTE C NR BORREGO SPRINGS CA	33 22 25	116 25 36	144.00	7/28/1951	2/15/1986	36
S118	10255850	VALLECITO C NR JULIAN CA	32 59 10	116 25 10	39.70	7/31/1964	8/15/1983	20
S119	10255885	SAN FELIPE C NR WESTMORLAND CA	33 07 26	115 51 08	1693.00	8/29/1961	8/26/1988	28
S137	10259000	ANDREAS C NR PALM SPRINGS CA	33 45 36	116 32 57	8.65	4/18/1949	12/25/2003	56
S140	10259200	DEEP C NR PALM DESERT CA	33 37 52	116 23 29	30.60	1962	12/29/2004	44
S141	10259300	WHITEWATER R A INDIO CA	33 44 14	116 14 07	1073.00	11/22/1965	1/11/2005	37
Region 3 - Antelope Valley								
S313	10264530	PINE C NR PALMDALE CA	34 36 09	118 14 48	1.78	1/6/1959	12/29/2004	42
S334	10264750	PINE TREE C NR MOJAVE CA	35 13 50	118 05 07	34.16	7/30/1959	1/16/1979	20

The accuracy of the hybrid regression analysis to predict the log-Pearson Type III results for stations with a long period of record was assessed using a root-mean-square error (RMSE) between the hybrid regression discharges and log-Pearson Type III flood-frequency flows. Table 6-3 shows the comparisons of RMSE for all annual exceedance probabilities. A RMSE was also calculated using the regression discharges computed from the WSP 2433 regression equation for Region 10 and the log-Pearson Type III flood frequency flows. The comparison of RMSEs (in log space) indicates that the hybrid regression equations have a higher accuracy than the conventional regression equations when compared to the log-Pearson Type III flood frequency flows. It should be noted that there is a significant difference in the RMSE results, although the differences in Table 6-3 do not appear to be as large because they are reported in log units.

The hybrid regression analysis was then extended by using additional peaks since Water Year 1986. Of the 52 stations, 12 stations have additional peaks. The total number of peaks from the 52 stations increased from 963 to 1120. In the extended hybrid regression analysis, the number of groups is seven, which again is the maximum number of groups minus one. The final hybrid regression equations (see Equations 6.2 through 6.7) are applicable to southern desert basins with drainage areas between 0.01 and 3,090 square miles, the mean annual precipitation less than or equal to 15 inches, and the mean basin elevation below 4,500 feet.

$$Q_2 = 8.57 A^{0.5668} \tag{6.2}$$

$$Q_5 = 80.32 A^{0.5410} \tag{6.3}$$

$$Q_{10} = 146.33 A^{0.5490} \tag{6.4}$$

$$Q_{25} = 291.04 A^{0.5939} \tag{6.5}$$

$$Q_{50} = 397.82 A^{0.6189} \tag{6.6}$$

$$Q_{100} = 557.31 A^{0.6619} \tag{6.7}$$

where Q is the discharge in cfs and A is the drainage area in square miles.

Table 6-3. Comparison of Current Study and USGS Regression Results.

Annual Exceedance Probability	Average Recurrence Interval (years)	RMSE in Log Space (Current Study)	RMSE in Log Space (USGS Regression)
0.5	2	0.1994	0.2027
0.2	5	0.1704	0.1829
0.1	10	0.1499	0.1826
0.04	25	0.1447	0.1675
0.02	50	0.1454	0.1592
0.01	100	0.1487	0.1610

6.2 Owens Valley/Mono Lake Region

A standard regression analysis was performed to derive a new set of regression equations for the Owens Valley/Mono Lake region. A standard regression analysis is valid because thunderstorms are not dominant in this region and adequate gage data are available. All stations that were used in WSP 2433 Regions 5 and 6 and are within the Owens Valley/Mono Lake desert region were identified. Of the 11 stations, 3 were not used due to having 8 or more years of zero peak flow with a maximum of 12 years of record. Station 10268700 was also not used because there appears to be significant infiltration in that basin, to a degree that flow at the gage is extremely low for a 20-square-mile drainage basin. This flow attenuation is not a typical characteristic of the other gages used. The remaining 7 gaging stations were used to develop regression equations for the area. Of the 7 stations selected, 6 stations have additional annual peaks since Water Year 1986. For these stations, an updated flood-frequency analysis was performed using the U.S. Army Corps of Engineers' Statistical Software Package HEC-SSP (Hydrologic Engineering Center, 2006a), based on Bulletin 17B, "Guidelines for Determining Flood Flow Frequency" (1982). Gaging stations used in the analysis are shown in Figure 6-2 and summarized in Table 6-4. The HEC-SSP output is included in Appendix D.

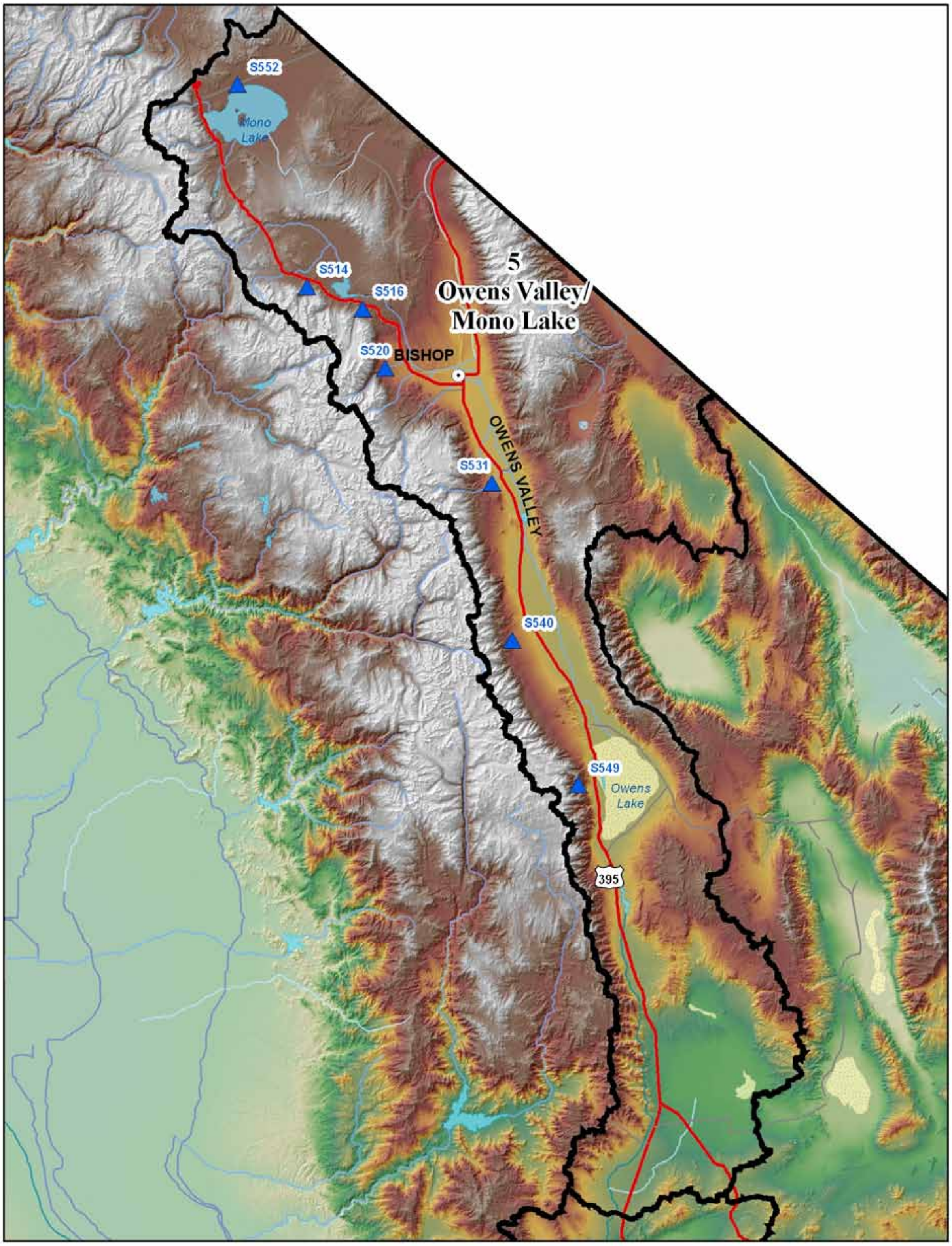


Figure 6-2. Owens Valley/Mono Lake Region Gaging Stations used in Regression Analysis.

Table 6-4. Owens Valley/Mono Lake Region Gaging Stations used in Regression Analysis.

Site no	Station Name	Basin Area (sq mi)	Decimal Latitude	Decimal Longitude	Years of Peak Flow Data	Elevation Index (ft)	New FFA Analysis Performed?	WEST ID
10265200	CONVICT C NR MAMMOTH LAKES CA	18.2	37.607	-118.849	53	10,000	Yes	S514
10265700	ROCK C A LITTLE ROUND VALLEY NR BISHOP CA	35.8	37.554	-118.685	52	10,500	Yes	S516
10267000	PINE C A DIVISION BOX NR BISHOP CA	36.4	37.416	-118.622	58	10,000	Yes	S520
10276000	BIG PINE C NR BIG PINE CA	39	37.145	-118.315	62	7,200	Yes	S531
10281800	INDEPENDENCE C BL PINYON C NR INDEPENDENCE CA	18.1	36.779	-118.265	56	9,000	Yes	S540
10286000	COTTONWOOD C NR OLANCHA CA	40.1	36.439	-118.081	68	10,000	Yes	S549
10287210	BRIDGEPORT C NR BODIE CA	13.1	38.079	-119.045	11	7,750	No	S552

The flood-frequency discharges at selected stations were correlated to the basin drainage area, mean basin elevation, and latitude of the gaged site, which is the same formulation used in WSP 2433 for Region 5 (note: the Owens Valley/Mono Lake region in the current study is coincidentally also referred to as Region 5). The coefficient and exponents in the regression equations were determined using a multiple regression analysis. The final regression equations are expressed as follows:

$$Q_2 = 0.007\,A^{1.839}\left[\frac{ELEV}{1000}\right]^{1.485}\left[\frac{LAT-28}{10}\right]^{-0.680} \tag{6.8}$$

$$Q_5 = 0.212\,A^{1.401}\left[\frac{ELEV}{1000}\right]^{0.882}\left[\frac{LAT-28}{10}\right]^{-0.030} \tag{6.9}$$

$$Q_{10} = 1.28\,A^{1.190}\left[\frac{ELEV}{1000}\right]^{0.531}\left[\frac{LAT-28}{10}\right]^{0.525} \tag{6.10}$$

$$Q_{25} = 9.70\,A^{0.962}\left[\frac{ELEV}{1000}\right]^{0.107}\left[\frac{LAT-28}{10}\right]^{1.199} \tag{6.11}$$

$$Q_{50} = 34.5\,A^{0.829}\left[\frac{ELEV}{1000}\right]^{-0.170}\left[\frac{LAT-28}{10}\right]^{1.731} \tag{6.12}$$

$$Q_{100} = 111\,A^{0.707}\left[\frac{ELEV}{1000}\right]^{-0.429}\left[\frac{LAT-28}{10}\right]^{2.241} \tag{6.13}$$

where Q is the discharge in cfs, A is the drainage area in square miles, $ELEV$ is the mean basin elevation in feet, and LAT is the latitude in decimal degrees at the station site.

Table 6-5 provides the standard error and coefficient of determination (r^2) for each of the recurrence interval regression equations.

Table 6-5. Regression Equation Statistics for Owens Valley/Mono Lake Region.

Average Recurrence Interval (years)	Standard Error, %	r^2
2	36	0.72
5	21	0.80
10	16	0.83
25	13	0.80
50	14	0.69
100	17	0.52

Figure 6-3 shows a comparison of the 100-year flows for the log-Pearson Type III flood frequency discharges, discharges calculated using the USGS WSP 2433 Region 5 regression equation, and those using the new regression equation (Equation 6.13). In general, the new regression equation follows the published WSP 2433 or newly updated log-Pearson Type III values much better than the USGS regression equation.

Please note that the USGS regression equations for WSP 2433 Region 5 included in the current Highway Design Manual (page 810-21, Caltrans 2006) contain an error. The exponents to the elevation term are missing.

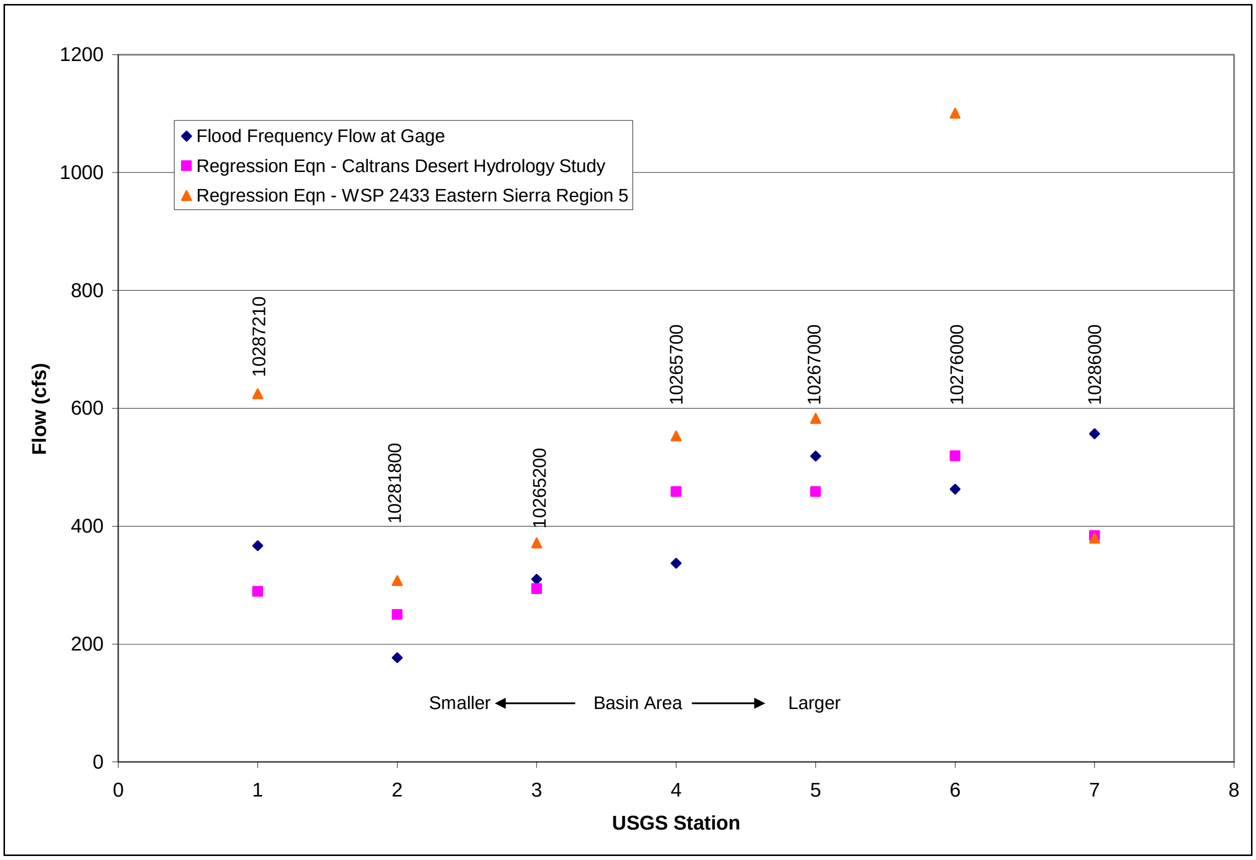


Figure 6-3. 100-year Flow Comparison for Owens Valley/Mono Lake Region.

6.3 Northern Basin and Range

A standard regression analysis was also performed to develop a new set of regression equations for the Northern Basin and Range region. Like the Owens Valley/Mono Lake region, a standard regression analysis is valid because thunderstorms are not dominant, and adequate gage data are available. All stations that were used in WRI 77-21 Northeast Region and/or WSP 2433 Region 2 but are within the Northern Basin and Range desert region were selected. If a station was included in both WSP 2433 and WRI 77-21, the flood-frequency peak discharges in WSP 2433 were used. If there are additional annual peaks that were not included in the WSP 2433 or WRI 77-21 studies, an updated flood-frequency analysis was performed.

Of the seventeen stations, five were identified as having less than 10 years of record. In addition, three stations have 10 or 11 years of data, but each contains at least 2 zero values. This left 9 stations for the regression analysis (see Figure 6-4 and Table 6-6). All these 9 stations were used in WRI 77-21 but not in WSP 2433.

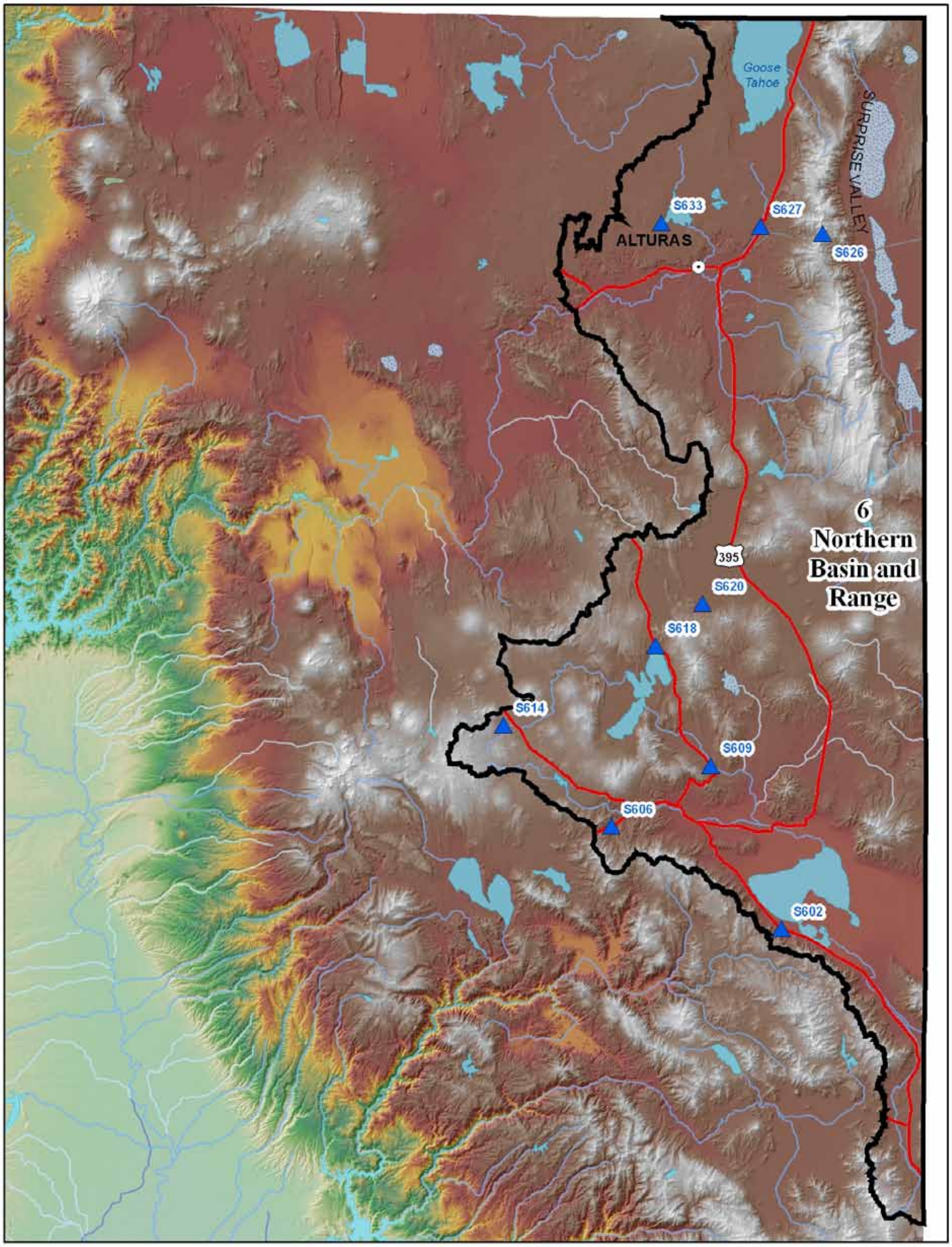


Figure 6-4. Northern Basin and Range Gaging Stations used in Regression Analysis.

Table 6-6. Northern Basin and Range Gaging Stations used in Regression Analysis.

Site no	Station Name	Basin Area (sq mi)	Decimal Latitude	Decimal Longitude	Years of Peak Flow Data	Elevation Index (ft)	New FFA Analysis Performed?	WEST ID
10354700	MILL C A MILFORD CA	2.26	40.171	-120.372	10	5,200	No	S602
10356300	WF WILLARD C TRIB NR WESTWOOD CA	0.83	40.374	-120.819	11	5,300	No	S606
10358470	WILLOW C TRIB NR SUSANVILLE CA	3.08	40.497	-120.559	11	5,600	No	S609
10359250	PINE C NR WESTWOOD CA	24.80	40.574	-121.106	22	6,400	Yes	S614
10359350	EAGLE LK TRIB NR SUSANVILLE CA	0.91	40.736	-120.707	11	5,600	No	S618
10359510	WHISKEY C NR TERMO CA	4.56	40.821	-120.584	11	6,000	No	S620
11342945	THOMS C NR CEDARVILLE CA	1.06	41.564	-120.269	11	7,100	No	S626
11342960	NF PIT R TRIB NR ALTURAS CA	2.36	41.576	-120.436	11	4,900	No	S627
11348080	BIG SAGE RES TRIB NR ALTURAS CA	2.54	41.583	-120.700	11	5,000	No	S633

The drainage area and elevation parameters published in WRI 77-21 were used for updating the regression equations for Northern Basin and Range Region 6. The final regression equations are expressed as follows:

$$Q_2 = 5.320\, A^{0.415} \left[\frac{H}{1000}\right]^{0.928} \tag{6.14}$$

$$Q_5 = 29.71\, A^{0.360} \left[\frac{H}{1000}\right]^{0.296} \tag{6.15}$$

$$Q_{10} = 85.76\, A^{0.314} \left[\frac{H}{1000}\right]^{-0.109} \tag{6.16}$$

$$Q_{25} = 275.5\, A^{0.253} \left[\frac{H}{1000}\right]^{-0.555} \tag{6.17}$$

$$Q_{50} = 616.9\, A^{0.281} \left[\frac{H}{1000}\right]^{-0.867} \tag{6.18}$$

$$Q_{100} = 1293\, A^{0.166} \left[\frac{H}{1000}\right]^{-1.154} \tag{6.19}$$

where Q is the discharge in cfs, A is the drainage area in square miles, and H is the altitude index in feet, defined as the average of the altitudes at points along the main channel of the stream located 10 and 85 percent of the distance from the site to the basin divide.

Table 6-7 provides the standard error and coefficient of determination (r^2) for each of the recurrence interval regression equations. Figure 6-5 shows a comparison of the 100-year log-Pearson Type III flood frequency flows, the discharges calculated using the USGS WRI 77-21 regression equation for the Northeast Region, and those using the new regression equation (Equation 6.19). The comparison indicates that the newly developed regression equations predict flows better than the USGS regression equations. However, Equations 6.14 through 6.19 should be used with caution as the coefficients of determination (r^2) are low. Given this uncertainty and the greater potential for under- or over-prediction, the development of a rainfall-runoff model may be preferable for watersheds in this region.

Table 6-7. Regression Equation Statistics for Northern Basin and Range.

Average Recurrence Interval (years)	Standard Error, %	r^2
2	37	0.29
5	30	0.29
10	26	0.28
25	23	0.24
50	22	0.20
100	21	0.18

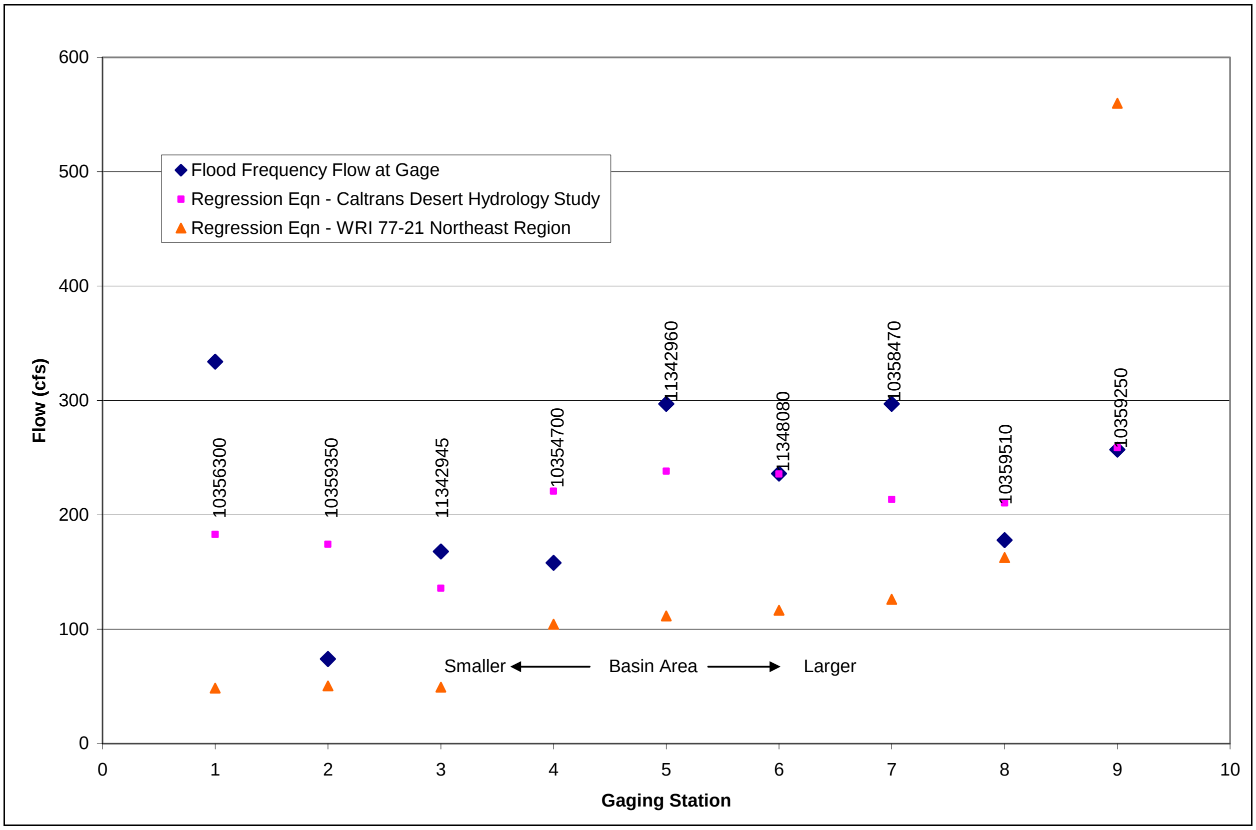


Figure 6-5. 100-year Flow Comparison for Northern Basin and Range Region.

6.4 Summary

Regional regression equations were developed specifically for California's desert regions based on a subset of data from USGS publications WSP 2433 and WRI 77-21.

One set of regional regression equations was developed for the southern desert regions (Colorado Desert, Sonoran Desert, Mojave Desert, and the Antelope Valley) based on a hybrid regional regression analysis, the same method used in WSP 2433 for Region 10. These equations were found to predict flows better than the WSP 2433 equations for these regions.

For the Owens Valley/Mono Lake region, a new set of regional regression equations was developed using standard regression analyses with a subset of data from WSP 2433 Regions 5 and 6. The coefficients of determination (r^2) for the new regression equations range from average to very good (0.52 to 0.83). In general, the new equations for this region provide better flow estimates than the WSP 2433 Region 5 regression equations.

For the Northern Basin and Range, a combination of data from WSP 2433 Region 2 and WRI 77-21 Northeast Region was used to develop new regression equations. While the newly developed regression equations predict flows better than the USGS regression equations, the coefficients of determination (r^2) are low. Therefore, there is significant uncertainty associated with the new regression equations for the Northern Basin and Range, and the development of a rainfall-runoff model may be preferable for ungaged watersheds in this region.

7 RATIONAL METHOD

For small basins, the Rational Method – or some variation – is commonly used to compute peak discharges. The popularity of the Rational Method is due to its simplicity. However, sufficient care is needed to ensure that the method is used correctly. This chapter describes the assumptions inherent to the Rational Method, the recommended drainage area limit for the method, and typical runoff coefficients for desert areas.

7.1 Method Assumptions

The Rational Method is based on the following assumptions:

- Peak flow occurs when the entire watershed is contributing to the flow.
- Rainfall intensity is the same over the entire drainage area.
- Rainfall intensity is uniform over a length of time equal to the time of concentration.
- Frequency of the computed peak flow is the same as that of the rainfall intensity, i.e., the 10-year rainfall intensity is assumed to produce the 10-year peak flow.
- The coefficient of runoff is the same for all storms of all recurrence probabilities.

For more details regarding the Rational Method, please refer to Section 819.2(1) of the Caltrans Highway Design Manual (2006).

7.2 Drainage Area Limit

Table 7-1 shows a summary of the upper limit of the drainage area within which the Rational Method is considered valid by different agencies. The area limit ranges from 20 to 640 acres. The current Caltrans Highway Design Manual (2006) limits the Rational Method to catchments less than 320 acres (0.5 mi^2). However, this limit is probably too high for semi-arid and arid areas.

The Rational Method assumes that the rainfall intensity is uniformly distributed over the entire drainage area at a uniform rate lasting for the duration of a storm. For small basins in the southern desert areas, the dominant storm is a local thunderstorm. Local thunderstorms are typically concentrated on a small area with the highest intensity in the eye or (center) of the storm. The intensity decreases rapidly with the distance from the storm eye. In addition, the storm usually moves quickly. Therefore, if the Rational Method is applied to a basin that is too large in area, the assumption is no longer valid.

A number of counties in the arid Southwest specify an upper limit of between 100 and 200 acres. It should be noted that this upper limit is not a strict value, but represents the area at which the Rational Method assumptions typically no longer apply, particularly in arid regions. The drainage area limits for Riverside, San Bernardino, and San Diego manuals reflect, in part, the emphasis of the hydrology manuals on the more urbanized, non-desert portions of those counties.

Given the assumptions of the Rational Method, an approximate upper limit of 160 acres (0.25 mi^2) is recommended for California's desert regions. This is the same limit used in Maricopa County (Phoenix area) and nearby Pinal County, and similar to that used in the Las Vegas area (Clark County). Although this limit is approximate in nature, strong consideration should be given to selecting another, more appropriate hydrologic method if the drainage area approaches or exceeds 160 acres.

In general, the Rational Method becomes less valid as the drainage area increases. Therefore, the 160-acre limit is also recommended for regions not dominated by convective storms. As an example, Washoe County (Reno area), Nevada – which is dominated by general storms – uses an even smaller (100-acre) limit.

Table 7-1. Summary of Upper Limit of Drainage Area for the Rational Method.

County/Agency	**Drainage Area**
Coconino County, AZ (Flagstaff area)	20 acres
Los Angeles County, CA	40 acres for standard Rational Method Any size for Modified Rational Method
Washoe County, NV (Reno area)	100 acres
Clark County, NV (Las Vegas area)	150 acres
Maricopa County, AZ (Phoenix area)	160 acres
Pinal County, AZ	160 acres
FHWA Hydraulic Design Series No. 2 ("Highway Hydrology")	200 acres
Nevada DOT	200 acres
Caltrans (Highway Design Manual)	320 acres
Riverside County, CA	500 acres
San Bernardino County, CA	640 acres
San Diego County, CA	640 acres

7.3 Rainfall Intensity

The rainfall intensity can be determined from the time of concentration and the rainfall intensity-duration-frequency data, which can be obtained from the following sources:

- NOAA Atlas 14 (preferred where available) – Data can be obtained on NOAA's Precipitation Data Frequency Server http://hdsc.nws.noaa.gov/hdsc/pfds/

- DWR Bulletin No. 195 (California Department of Water Resources, 1976; with periodic updates since 1976).

A comparison of NOAA Atlas 14 and DWR Bulletin No. 195 is provided in Section 8.1.3. While the use of NOAA Atlas 14 is preferred, DWR Bulletin No. 195 is an acceptable alternative.

7.4 Runoff Coefficients

Table 7-2 provides runoff coefficients ("C" values) that apply specifically to desert areas. These coefficients are applicable for storms with 2- to 10-year return intervals, and must be adjusted for larger, less frequent storms by multiplying the coefficient with an appropriate frequency factor, as described in Section 819.2 of the Highway Design Manual. The frequency factors for the 25-year, 50-year, and 100-year return intervals are 1.1, 1.2, and 1.25, respectively. The product of the frequency factor and the runoff coefficient should never exceed 1.0; however, an upper limit of 0.95 rather than 1.0 is recommended (Maricopa County, 2003).

The runoff coefficients listed in Table 7-2 may be used in conjunction with those listed in Table 819.2B of the Highway Design Manual.

Table 7-2. Runoff Coefficients for Desert Areas (adapted from Maricopa County, 2003).

Type of Drainage Area	**Runoff Coefficient[1]**
Undisturbed Natural Desert or Desert Landscaping (without impervious weed barrier)	0.30 – 0.40
Desert Landscaping (with impervious weed barrier)	0.55 – 0.85
Desert Hillslopes	0.40 – 0.55
Mountain Terrain (slopes greater than 10%)	0.60 – 0.80

1. Runoff coefficients are for 2 to 10-year storms and must be adjusted by appropriate frequency factor: 1.1 for 25-year storm, 1.2 for 50-year storm, and 1.25 for 100-year storm. Resulting coefficients should not exceed 0.95.

7.5 Summary

Given the assumptions of the Rational Method, an approximate upper limit of 160 acres (0.25 mi^2) is recommended for California's desert regions. Although this limit is approximate in nature, strong consideration should be given to selecting another, more appropriate hydrologic method if the drainage area approaches or exceeds 160 acres.

Rainfall intensity-duration-frequency data used for the Rational Method can be obtained from either NOAA Atlas 14 or DWR Bulletin No. 195. Runoff coefficients have been provided for a number of typical desert terrain/vegetation types.

8 RAINFALL-RUNOFF SIMULATION: METHODS AND PARAMETERS

Due to the lack of recorded discharge data in desert areas, determination of design discharges is often performed using a rainfall-runoff approach. All counties in and around California's desert regions recommend using a rainfall-runoff approach, including San Diego County (2003), Los Angeles County (2006a), Riverside County (1978), and San Bernardino County (1986) in California, Maricopa County (2003) in Arizona, and Clark County (1999) in Nevada.

A rainfall-runoff approach uses a numerical model to simulate the rainfall-runoff process and generate discharge hydrographs. It involves four main components: rainfall, rainfall losses, transformation of effective rainfall, and channel routing. Each component is described in the following sections.

8.1 Rainfall

In a rainfall-runoff approach, a key element in the quantification of stormwater runoff from semi-arid and arid regions is the proper characterization of the rainfall volume and the spatial/temporal distribution of rainfall for a design storm. Important considerations include rainfall depth-duration-frequency characteristics, depth-area reduction, and temporal distributions.

8.1.1 Design Rainfall Criteria

In the rainfall-runoff simulation, it is often assumed that a storm with a certain return period produces basin runoff with the same return period. For example, a 100-year storm is assumed to generate the 100-year flood.

A design storm often represents a critical storm that produces a flood discharge that will be used in the design of infrastructure such as bridges and culverts at an appropriate flood protection level. The design rainfall criteria include the storm frequency and duration. Table 8-1 summarizes the design storm frequencies and durations used by counties in and around southern California. The majority of the counties require that major drainage facilities be designed to accommodate a storm event having a 1% chance of being equaled or exceeded in any given year (recurrence interval of 100 years).

The selection of an appropriate duration for a design storm depends on a number of factors, including the size of the watershed, the type of rainfall-runoff approach, and hydrologic characteristics of the study watershed. As shown in Table 8-1, a number of counties recommend using different durations for different basin sizes or different storm types. This approach is also recommended in this study for selecting design storm durations.

As discussed in Chapter 3, for the southern portion of California's desert areas (Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert regions) the critical flood-producing storm is the local thunderstorm with durations generally less than 6 hours. Review of the largest historical peaks in southern California indicates that most of these peaks occurred in small watersheds with drainage areas less than 20 square miles. A storm of 6-hour duration will account for almost all of the volume produced by summer thunderstorms. These 6-hour design storms contain intense rainfall for the shorter durations as well, so that they also represent the critical storms in producing peak discharges.

For drainage areas between 20 and 100 square miles, the critical storm could be a local thunderstorm or a general storm, as either could produce the greatest flood peak discharges or the maximum flood volumes. Therefore, it is necessary to consider both general storms and local storms. A general storm usually covers a larger area and has a longer duration. A 24-hour general storm is often selected. For drainage areas larger than 100 square miles, a general storm typically produces the largest peak discharge and runoff volumes.

For the northern portion of the study area, which includes the Owens Valley/Mono Lake and Northern Basin and Range regions, a general winter storm is typically dominant. Therefore, the design storm should be the 24-hour general storm. There are no drainage area restrictions; the general storm is used for all watersheds in the northern regions. Table 8-2 summarizes the recommended durations for the design storms in the study area.

Table 8-1. Design Storm Frequency and Duration Used by Different Counties.

County/Agency	Frequency	Duration
Clark County, NV	100-year for bridges, culverts	6-hour
Los Angeles County, CA	50-year frequency design storm falling on a saturated watershed	24-hour
Maricopa County, AZ	100-year	2-hour (for the design of stormwater storage facilities) 6-hour (≤ 20 mi^2) 6- and 24-hour (between 20 and 100 mi^2) 24-hour (between 100 and 500 mi^2)
Riverside County, CA	100-year	3-hour and 6-hour for local thunderstorms 24-hour for general storms (All three design storms are evaluated and the maximum peak discharge is used)
San Bernardino County, CA	100-year	Peak 3-hours of the 24-hour storm (< 5 mi^2) 24-hour storm (≥ 5 mi^2)
San Diego County, CA	50-year for drainage upstream of any major roadway; 100-year for all design storms at a major roadway, crossing the roadway and thereafter	6-hour (using the Rational Method) 24-hour (using SCS Unit Hydrograph)

Table 8-2. Recommended Design Storm Durations for Desert Regions.

Region	**Duration** (based on watershed size)
Southern Regions (Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert)	6-hour local storms (≤ 20 mi^2) 6-hour local storm and 24-hour general storm (between 20 and 100 mi^2); use larger of the two peak discharges 24-hour general storm (> 100 mi^2)
Northern Regions (Owens Valley/ Mono Lake and Northern Basin and Range)	24-hour general storm

8.1.2 Depth-Duration-Frequency Characteristics

A rainfall-runoff model requires rainfall depths for a given precipitation frequency and duration, often referred to as the depth-duration-frequency statistics. In the past, most counties in the arid Southwest used the NOAA Precipitation-Frequency Atlas of the Western United States (Miller et al., 1973), often cited as NOAA Atlas 2. This atlas was published in 1973, and was based upon various precipitation data (up to 1968) from recording and non-recording rain gages reported to the U.S. Weather Bureau and its successor, the National Weather Service which is under NOAA. NOAA Atlas 2 gives isopluvials of 6- and 24-hour maximum rainfall totals for recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100-years. These isopluvials were derived through precipitation frequency analysis that reflected variations in topographic factors such as land slope, orographic barriers to air flow, land elevation, distance to source of moisture, location, and surface roughness. The atlas also contains formulas for the determination of the 1-hour precipitation at 2- and 100-year frequencies, coefficients for reducing the 1-hour precipitation to durations of 5, 10, 15, and 30 minutes, and nomographs for interpolation of the precipitation depths for any duration between 1 and 24 hours and any return period between 2 and 100 years.

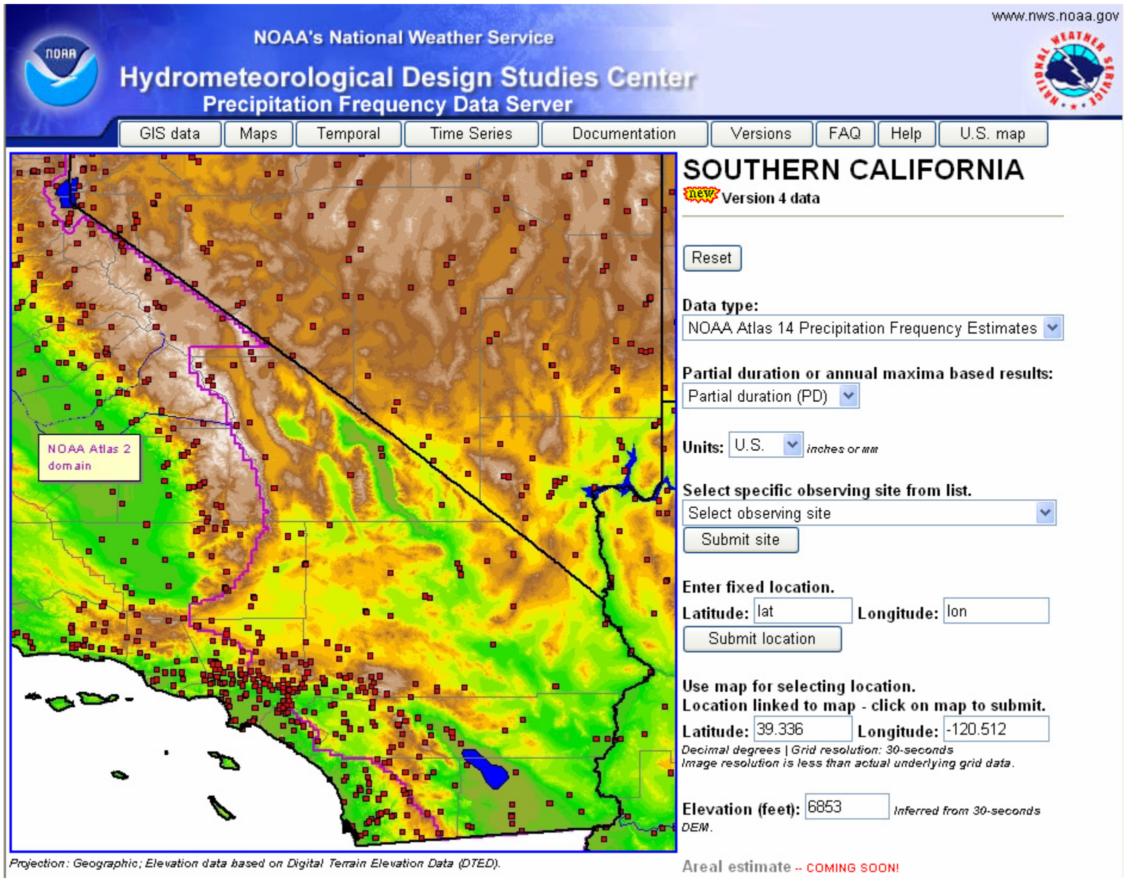
In 2004, NOAA published updated precipitation-frequency estimates for Arizona, Nevada, New Mexico, Utah, and southeastern California (Imperial, Inyo, eastern Kern, eastern Los Angeles, Riverside, San Bernardino, and eastern San Diego counties), often cited as NOAA Atlas 14 (Bonnin et al., 2004). NOAA Atlas 14 now supersedes information contained in NOAA Atlas 2 and other publications. The atlas provides precipitation frequency estimates for 5-minute through 60-day durations at average recurrence intervals of 2 years through 1,000 years. The results are provided at high spatial resolution and include confidence limits for the estimate.

The new estimates are based on improvements in three primary areas: denser data networks with a greater period of record (through 2000), the application of regional frequency analysis using L-moments for selecting and parameterizing probability distributions, and new techniques for spatial interpolation and mapping. The new techniques for spatial interpolation and mapping account for topography and have allowed significant improvements in areas of complex terrain.

NOAA Atlas 14 precipitation frequency estimates for the southwestern United States are available via the Precipitation Frequency Data Server (http://hdsc.nws.noaa.gov/hdsc/pfds), which provides the additional ability to download digital files. The types of results and information found there include (see Figure 8-1):

- Point estimates (via a point-and-click interface)
- ESRI shapefiles and ArcInfo ASCII grids
- Color cartographic maps: all possible combinations of frequencies (2-year to 1,000-year) and durations (5-minute to 60-day)
- Associated Federal Geographic Data Committee-compliant metadata
- Data series used in the analyses: annual maximum series and partial duration series
- Temporal distributions of heavy precipitation (6-hour, 12-hour, 24-hour and 96-hour)
- Seasonal exceedance graphs: counts of events that exceed the 1 in 2, 5, 10, 25, 50 and 100 annual exceedance probabilities for the 60-minute, 24-hour, 48-hour, and 10-day durations

NOAA Atlas 14 provides much more reliable estimates of precipitation-frequency data than NOAA Atlas 2. It provides both depth-duration-frequency and intensity-duration-frequency data.



SOUTHERN CALIFORNIA

new Version 4 data

Data type: NOAA Atlas 14 Precipitation Frequency Estimates

Partial duration or annual maxima based results: Partial duration (PD)

Units: U.S. *inches or mm*

Select specific observing site from list.
Select observing site

Enter fixed location.
Latitude: lat Longitude: lon

Use map for selecting location.
Location linked to map - click on map to submit.
Latitude: 39.336 Longitude: -120.512
Decimal degrees | Grid resolution: 30-seconds
Image resolution is less than actual underlying grid data.

Elevation (feet): 6853 *Inferred from 30-seconds DEM.*

Projection: Geographic; Elevation data based on Digital Terrain Elevation Data (DTED).

Areal estimate -- COMING SOON!

Figure 8-1. NOAA Precipitation Frequency Data Server (NOAA Atlas 14).

8.1.3 NOAA Atlas 14 vs. DWR Bulletin No. 195

Bulletin No. 195 (California Department of Water Resources, 1976; with periodic updates since 1976) is often used by Caltrans engineers to obtain depth-duration-frequency data for watersheds in California. The Pearson Type III distribution is used in Bulletin No. 195 to model all storm durations.

For desert regions, the use of NOAA Atlas 14 is recommended over Bulletin No. 195 because the National Weather Service used a state-of-the-art L-moment approach rather than using only the Pearson Type III distribution. Bonnin et al. (2004) describe the following characteristics and benefits of the L-moment method:

- Provides great utility in choosing the most appropriate probability distribution to describe the precipitation frequency estimates

- Increases accuracy by estimation of shape parameters from the combination of data from all stations in a homogeneous region rather than from each station individually, vastly increasing the amount of information used to produce the estimate

- Employs data from many stations in a region to estimate frequency distribution curves for the underlying population at each station. The approach assumes that the frequency distributions of the data from many stations in a homogeneous region are identical apart from a site-specific scaling factor.

- Assists in selecting the appropriate probability distribution and the shape of the distribution from regional frequency analysis, but precipitation frequency estimates (quantiles) are estimated uniquely at each individual station by using a scaling factor, which, in this project, is the mean of the annual maximum series, at each station. The resulting quantiles are more reliable than estimates obtained based on single at-site analysis.

- Is less affected by the sampling variability and, in particular, the presence of outliers in the data compared to Moments of Product or the Conventional Moments Method (CMM) used in previous NWS publications such as NOAA Atlas 2. Sample moment estimates based on the CMM have some undesirable properties. The higher order sample moments such as the third and fourth moments associated with skewness and kurtosis, respectively, can be severely biased by limited data length. The higher order sample moments also can be very sensitive or unstable to the presence of outliers in the data.

- Describes probability distributions using coefficient of L-variation, L-skewness, and L-kurtosis, which are analogous to their CMM counterparts. Coefficient of L-variation provides a measure of dispersion. L-skewness is a measure of symmetry. L-kurtosis is a measure of peakedness.

- Computes site-specific quantiles for each frequency and duration. Because the scale-free frequency distribution parameters are estimated from regionalized groups of observed data, the result is a dimensionless frequency distribution common to the N stations in the region. Applying the site-specific scaling factor (the mean) to the dimensionless distribution (regional growth factors) yields site-specific quantiles.

Instead of using a single distribution, the best probability distribution for each homogeneous region for each frequency event was used by NOAA, whether it was the Generalized Extreme Value (GEV), Generalized Logistic (GLO), Generalized Normal (GNO), Generalized Pareto (GPA), or Pearson Type III (PE3).

While the NOAA Atlas 14 rainfall analysis is considered better than that used in DWR Bulletin No. 195, the latter still provides reasonable rainfall estimates based on generally accepted hydrologic methods. For areas where NOAA Atlas 14 data are not available, data from Bulletin No. 195 should be used.

8.1.4 Depth-Area Reduction

The rainfall depths from the NOAA Atlas 2 isopluvial maps are point rainfall amounts for specified frequencies and durations. These rainfall depths are expected to occur at a specific point or points in a watershed for the specified frequency and duration. This depth is not the areally-averaged rainfall over the basin that would occur during a storm. A reduction factor is used to convert the point rainfall to an equivalent uniform depth of rainfall over the entire watershed. As the watershed area increases, the reduction increases, reflecting the greater nonhomogeneity of rainfall for storms of larger areas. It should be noted that NOAA Atlas 14 provides high resolution of depth-duration-frequency data in an ASCII grid format and allows one to calculate accurately an arithmetic mean of the grid cells within a watershed. However, the mean is still subject to an areal-reduction factor to compute the areal precipitation estimate for each frequency. NOAA is currently updating previously developed areal reduction factors (personal communication with Tye Parzybok, NOAA on October 12, 2006, one of the Atlas 14 authors). However, the new factors are not yet available at the time of this study.

In the meantime, currently available approaches can be used to adjust the point-based rainfall depths. Table 8-3 shows the methods used by different counties. There are two methods that have been applied to develop area reduction curves. The first approach is to use curves included in NOAA Atlas 2. The second approach is to use the curve included in the National Weather Service HYDRO-40 (Zehr and Myers, 1984). There is a general consensus among hydrometeorologists that for the southwestern United States, the depth-area curves from NWS HYDRO-40 are more representative of desert thunderstorm conditions than are the curves from the earlier NOAA Atlas 2 (USACE, 1988, and Zeller, 1990). Therefore, the depth-area curve from NWS HYDRO-40 is recommended for use in the southern desert regions (Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert). The curve from NOAA Atlas 2 is recommended for the northern regions (Owens Valley/Mono Lake and Northern Basin and Range) as it better characterizes the spatial distribution of general storm rainfall.

Table 8-3. Methods of Determining Rainfall Area Reduction Factors.

County	Method
Clark County, NV	Based on National Weather Service HYDRO-40
Maricopa County, AZ	Based on the August 19, 1954 Queen Creek Storm (USACE, 1974) for 6-hour local storms Based on National Weather Service HYDRO-40 for 24-hour storms
Riverside County, CA	Based on NOAA Atlas 2
San Diego County, CA	Based on NOAA Atlas 2

8.1.5 Temporal Distribution

Besides the rainfall depth and its spatial distribution, the temporal distribution of a storm is another important element for a design storm. As shown in Table 8-4, there are three approaches that have been used in arid and semi-arid areas to distribute rainfall over time. The first is called a nested or balanced storm pattern according to HEC TD-15 (HEC, 1982), normally used for the 24-hour duration synthetic critical storm. It is composed of peak rainfall intensities for a specific return frequency (e.g., peak 5-minutes, 30-minutes, 1-hour, 3-hour, 6-hour, and 24-hour from NOAA Atlas 2) nested together with the peak 5-minutes of rainfall defined to occur at hour 16 of the 24-hour storm. Figure 8-2 shows the San Diego County 24-hour nested storm pattern. Use of a balanced storm permits the construction and arrangement of a storm event such that an average rainfall intensity is provided for all durations. A nested duration design storm ensures that each watershed will receive the design frequency depth of rainfall for its critical duration.

The second approach is to use the standard SCS Type II distribution (SCS, 1986). The SCS distribution was based on generalized rainfall depth-duration curves. All design storms developed with this method, regardless of duration, are based on the 24-hour volume for a given frequency and location.

The third approach is to develop a temporal distribution based on recorded precipitation data in a region. This is the preferred approach since it is directly based on the actual precipitation data. This is especially important for summer thunderstorms as the placement of rainfall with time significantly affects the rainfall intensity, a distinct feature of a thunderstorm (Zeller, 1990). Tyrrell and Hasfurther (1983) used a similar approach to develop dimensionless design mass curves for thunderstorms in Wyoming.

Table 8-4. Methods of Determining Rainfall Temporal Distribution.

County	**Method**
Clark County, NV	Based on limited precipitation data in the Las Vegas area. Three separate distributions are used for drainage areas less than 8 mi^2, between 8 and 12 mi^2, and greater than 12 mi^2, respectively.
Maricopa County, AZ	There are 5 dimensionless storm patterns for 6-hour storms. Pattern No. 1 was derived from rainfall statistics found in the NOAA Atlas 2 and Arkell and Richards (1986) for the Phoenix Sky Harbor Airport. Pattern Numbers 2 through 5 are modifications of the U.S. Army Corps of Engineers (1974) analysis of the Queen Creek storm of August 19, 1954. The 24-hour storm distribution is the SCS Type II distribution.
Los Angeles County, CA	24-hour pattern based on rainfall data in Los Angeles County and a modified alternating block method.
Riverside County, CA	3- and 6-hour patterns based on the Indio area thunderstorm of September 24, 1939. 24-hour patterns based on the general storm of March 1938.
San Diego County, CA	Nested 24-hour storm pattern based on HEC TD-15 (Hydrologic Engineering Center, 1982).
San Bernardino County, CA	Nested 24-hour storm pattern based on SCS 24-hour storm pattern and HEC TD-15.

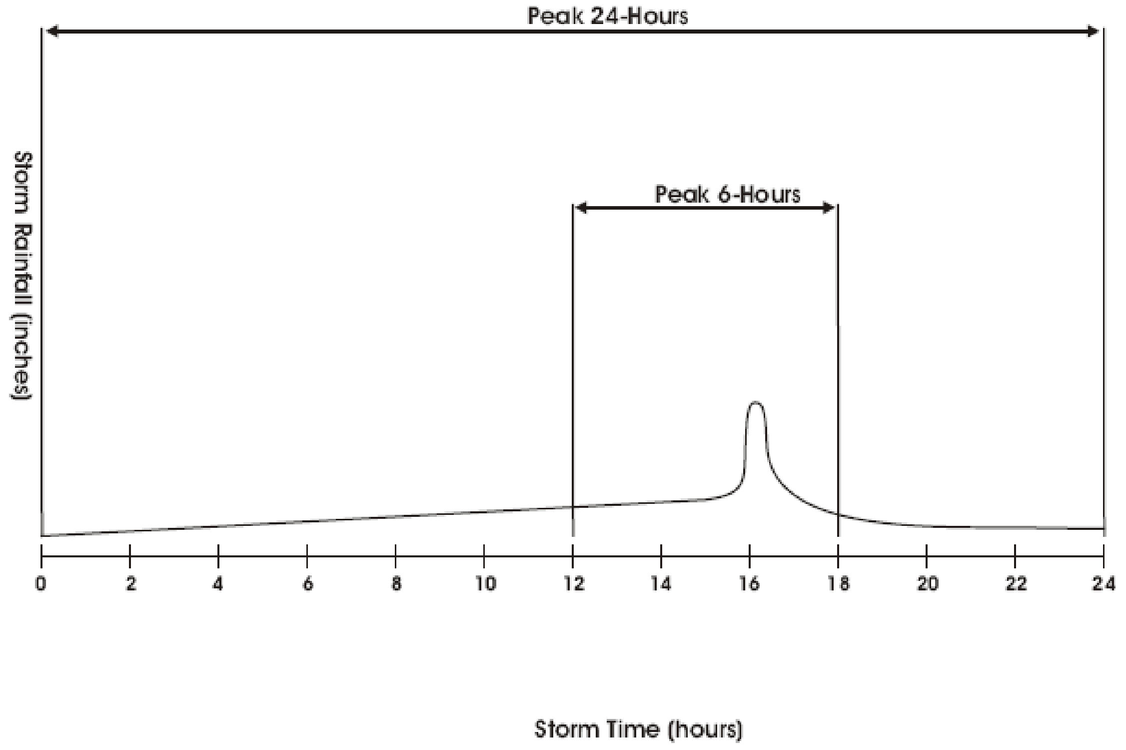


Figure 8-2. Sample 24-Hour Storm Temporal Pattern (San Diego County Hydrology Manual, 2003).

As a part of the Atlas 14 project, NOAA also developed temporal distributions of heavy precipitation for use with precipitation frequency estimates for 6-, 12-, 24- and 96-hour durations covering the semi-arid southwestern United States. The temporal distributions are expressed in probabilistic terms as cumulative percentages of precipitation and duration at various percentiles. The starting time of precipitation accumulation was defined in the same fashion as it was for precipitation frequency estimates for consistency.

The NOAA Atlas 14 project area was divided into two regions (convective versus general storms), as shown in Figure 8-3. Temporal distributions for the 6-hour duration are presented in Figure 8-4 and Figure 8-5. The curves for the convective precipitation area have steeper gradients than the curves for the general precipitation area for all durations and quartiles. The data were subdivided into quartiles based on where in the distribution the most precipitation occurred. This was done in order to provide more specific information on the varying distributions that were observed (Figure 8-6 and Figure 8-7).

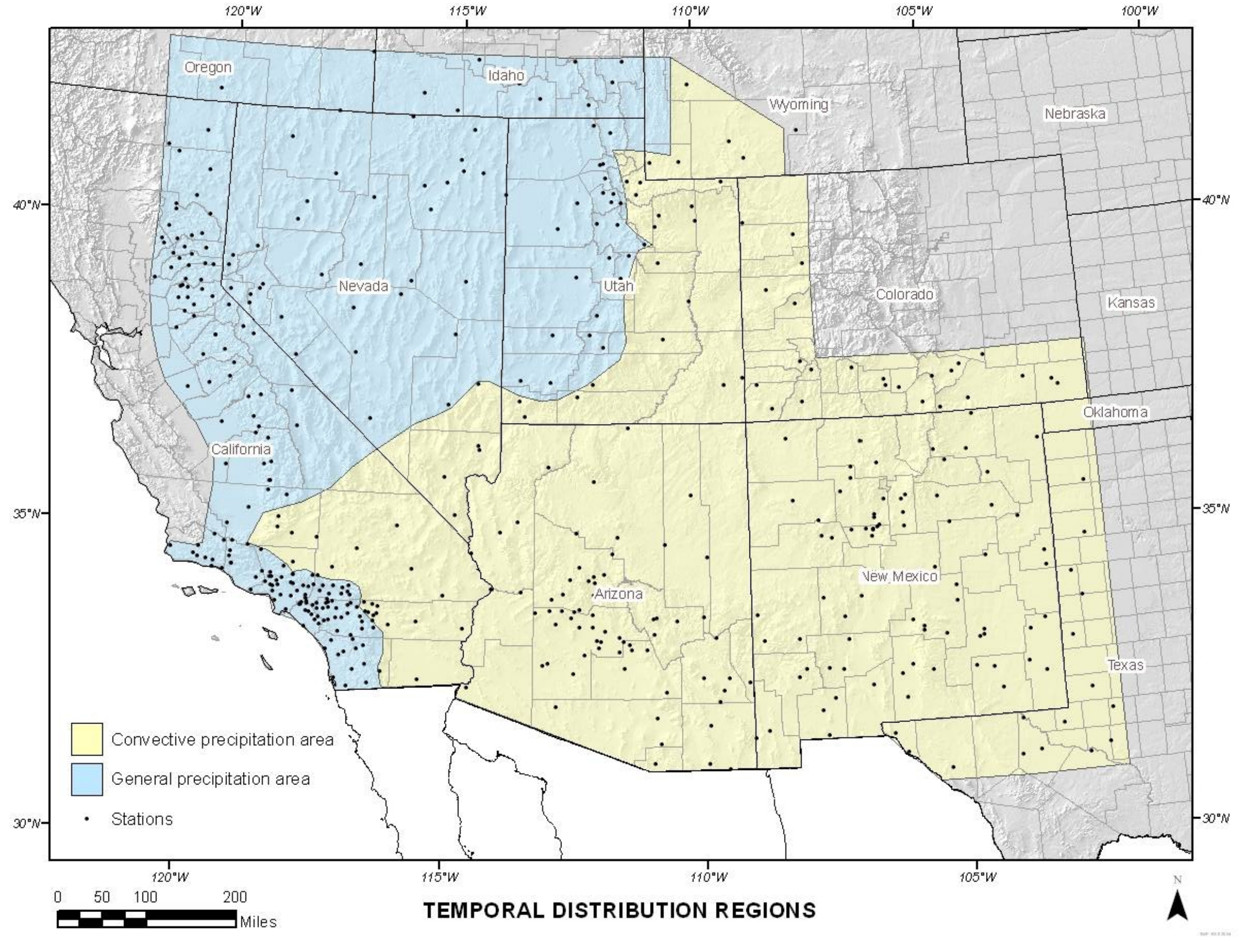


Figure 8-3. Temporal Distribution Regions (NOAA Atlas 14).

The data on the graphs (Figure 8-4 and Figure 8-5) represent the average of many events illustrating the cumulative probability of occurrence at 10% increments. For example, the 10% of cases in which precipitation is concentrated closest to the beginning of the time period will have distributions that fall above and to the left of the 10% curve. At the other end of the spectrum, only 10% of cases are likely to have a temporal distribution falling to the right and below the 90% curve. In these latter cases the bulk of the precipitation falls toward the end of the time period. The 50% curve represents the median temporal distribution on each graph.

First-quartile graphs (Figure 8-6 and Figure 8-7) consist of cases where the greatest percentage of the total precipitation fell during the first quarter of the time period, i.e., the first 1.5 hours of a 6-hour period, the first 3 hours of a 12-hour period, etc. The second, third and fourth quartile plots, similarly are for cases where the most precipitation fell in the second, third or fourth quarter of the time period.

NOAA Atlas 14 provides temporal distributions in probabilistic terms as cumulative percentages of precipitation and duration at various percentiles, allowing flexibility of use and maximization of runoff from a given storm volume.

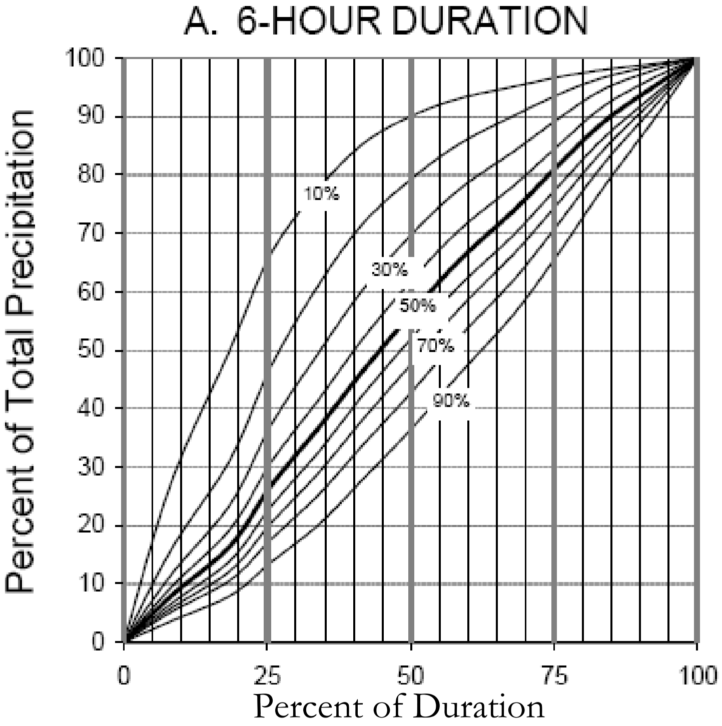


Figure 8-4. Temporal Distribution of 6-hour General Storms (NOAA Atlas 14).

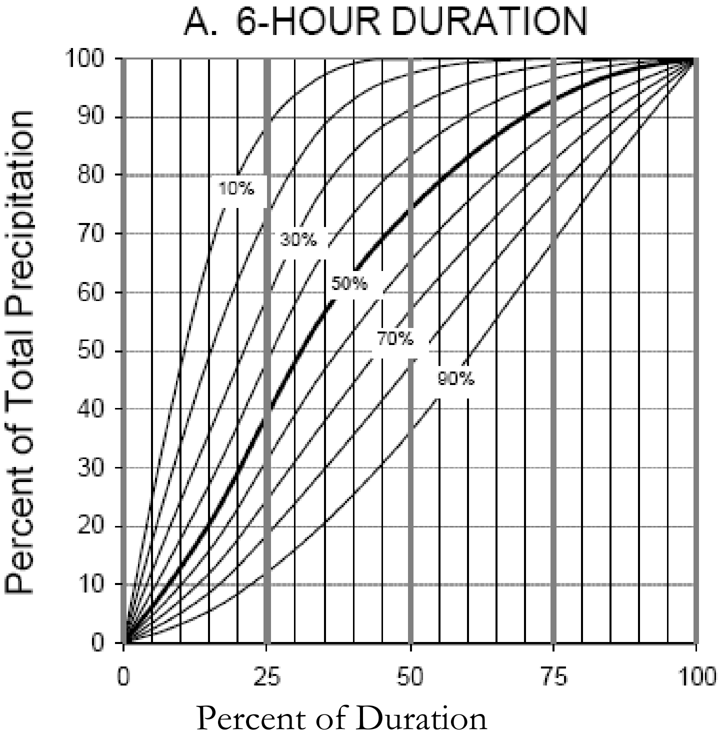


Figure 8-5. Temporal Distribution of 6-hour Convective Storms (NOAA Atlas 14).

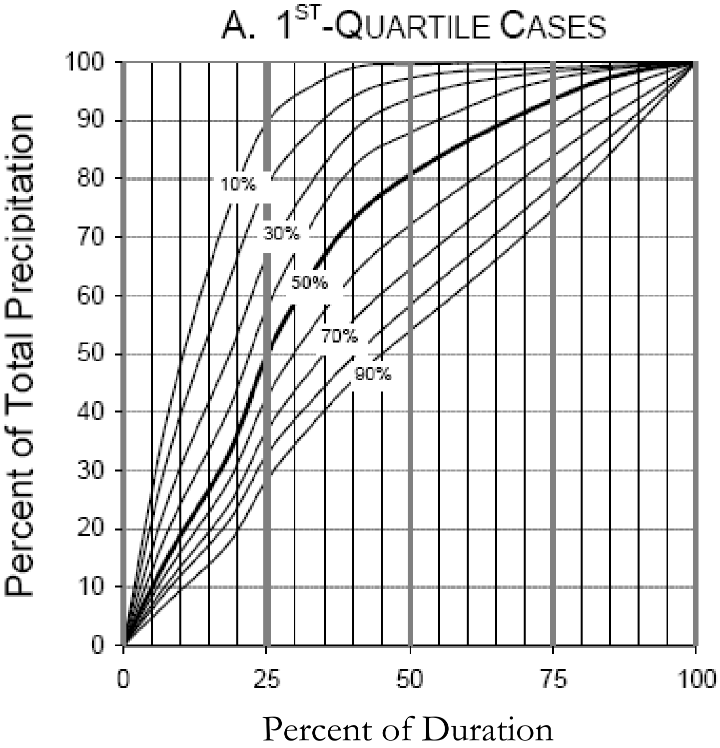


Figure 8-6. Temporal Distribution of 1st Quartile 6-hour General Storms (NOAA Atlas 14).

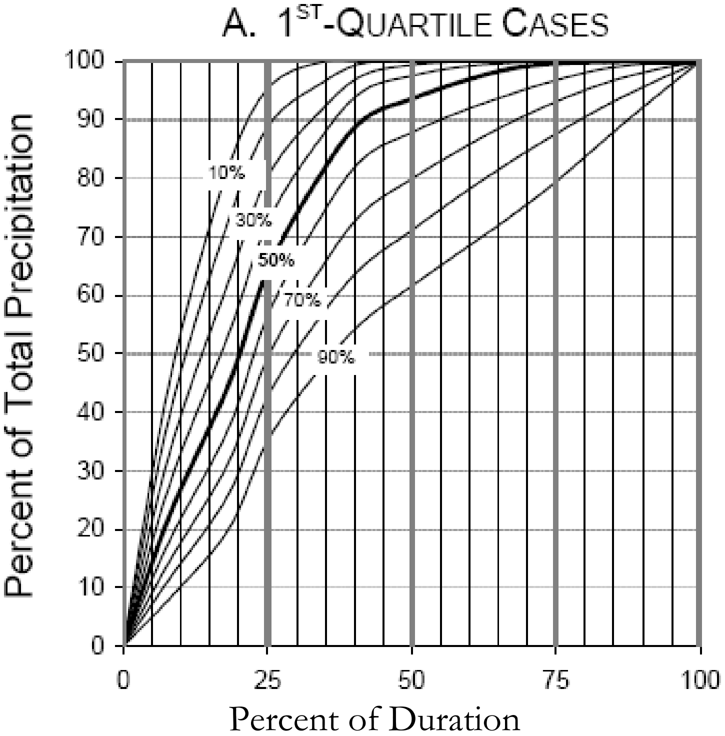


Figure 8-7. Temporal Distribution of 1st Quartile 6-hour Convective Storms (NOAA Atlas 14).

8.2 Rainfall Losses

Rainfall losses include depression storage, interception and transpiration by vegetation, minor amounts of evaporation, and infiltration. Infiltration is the process of water entering the soil surface and percolating downward into the soil where it is stored during a precipitation event. Subsequently, the stored soil water may be consumptively used by vegetation, percolate further downward to groundwater storage, or exit the soil surface as seeps or springs.

8.2.1 Loss Methods

Table 8-5 provides a summary of loss methods used by different counties and agencies. Only a very brief discussion for each method is included. Many references, such as HEC (1998), HEC (2006b), and Bedient and Huber (1992), describe these loss methods in detail. Table 8-6 summarizes the advantages and disadvantages for each loss method. Some of the material in this table was taken from HEC (2000).

Common loss methods include the following:

- Initial and Uniform Loss Rate
- Exponential Loss Rate
- SCS Curve Number
- Holtan Loss
- Green and Ampt Loss

The initial and uniform loss method is very simple but still appropriate for watersheds that lack detailed soil information. The initial loss specifies the amount of incoming precipitation that will be infiltrated or stored in the watershed before surface runoff begins. There is no recovery of the initial loss during periods without precipitation. The uniform rate determines the rate of infiltration that will occur after the initial loss is satisfied. The same rate is applied regardless of the length of the simulation.

The exponential loss rate method is an empirical method that relates loss rate to rainfall intensity and accumulated losses. It represents incremental infiltration as a logarithmically decreasing function of accumulated infiltration. Accumulated losses are representative of the soil moisture storage. The U.S. Army Corps of Engineers is the main user of the exponential rate method.

The Soil Conservation Service (now the Natural Resources Conservation Service) curve number method was originally intended to calculate total infiltration during a storm. It has been used to compute incremental precipitation during a storm by recalculating the infiltration volume at the end of each time interval. For modeling purposes, watershed losses are grouped into infiltration and an initial abstraction that includes all the losses except infiltration. The initial abstraction defines the amount of precipitation that must fall before surface runoff can begin.

The Holtan loss method is an exponential decay type of equation for which the rainfall loss rate asymptotically diminishes to the minimum infiltration rate. Although the loss equation is empirical, it includes all the factors that should be considered in an infiltration process. This is the only method of those described in this report that accounts for the redistribution of soil moisture. The available soil moisture storage is decreased by the amount of infiltration and increased by the percolation rate.

The Green and Ampt infiltration method is essentially a simplification of the comprehensive Richards' equation (Richards, 1931) for unsteady water flow in soil. It considers the physical properties of the soil to calculate the losses. This method does not consider the redistribution of soil moisture from upper to lower layers of soil strata. In addition, it does not consider the effects of ground cover on infiltration. The Green and Ampt method assumes the soil is initially at uniform moisture content, and infiltration takes place with so-called piston displacement. The method automatically accounts for ponding on the surface. The Green and Ampt infiltration method is the preferred method in Maricopa County, AZ. A detailed procedure to estimate the loss parameters and apply the method is provided in the Maricopa County Drainage Design Manual (2003).

Table 8-5. Summary of Rainfall Loss Method Recommended by Counties/Agencies.

County/Agency	**Method**
Clark County, NV	SCS Curve Number
Maricopa County, AZ	Green and Ampt infiltration equation Initial Loss and Uniform Loss Rate
Los Angeles County, CA	Uniform Loss Rate
Los Angeles District, USACE	Initial Loss and Uniform Loss Rate Exponential Loss Rate
Riverside County, CA	SCS Curve Number
San Diego County, CA	SCS Curve Number
San Bernardino County, CA	SCS Curve Number

Table 8-6. Pros and Cons of Various Loss Methods.

Method	**Pros**	**Cons**
Initial and Uniform Rate	• "Mature" model that has been used successfully in hundreds of studies throughout the U.S. • Easy to set up and use. • Model requires few parameters.	• Difficult to apply to ungaged areas due to lack of direct physical relationship of parameters and watershed properties. • Model may be too simple to predict losses within event, even if it does predict total losses well.
Exponential Loss Rate	• Easy to set up and use. • Model requires few parameters.	• An empirical model that is mainly used by USACE. • Needs calibration to be used effectively. • Not much experience and data on parameter estimation.
SCS Curve Number	• Simple, predictable, and stable method. • Relies on only one parameter (the curve number), which varies as a function of soil group, land use and treatment, surface condition, and antecedent moisture condition. • Features readily grasped and reasonable well-documented inputs. • Well established method, widely accepted for use in U.S. and abroad (from Ponce and Hawkins, 1996).	• Predicted values not consistent with classical unsaturated flow theory. • Infiltration rate will approach zero during a storm of long duration, rather than constant rate as expected. • Developed with data from small agricultural watersheds in the midwestern U.S., so applicability elsewhere is uncertain. • Default initial abstraction (0.2S) does not depend upon storm characteristics or timing. Thus, if used with design storm, abstraction will be same with all frequency storms. • Rainfall intensity not considered (Same loss for 25 mm rainfall in 1 hour or in 1 day.)
Holtan Loss	• Includes parameters that have a physical basis (deep percolation rate) with empirical ones such as an exponent controlling infiltration capacity as function of storage. • Some parameters can be estimated for ungaged watersheds from soils data.	• Not widely used, so less mature, not as much experience in professional community. • Requires more parameters than simple empirical models. • Method not included in HEC-HMS.
Green and Ampt Loss	• Physically-based model. • Parameters can be estimated for ungaged watersheds from information about soils.	• Not widely used, so less mature, not as much experience in professional community. • Requires more parameters than simple empirical models.

8.2.2 Method Selection

Selecting a loss method and estimating the required model parameters are critical steps in developing a rainfall-runoff model. This is particularly important in desert areas as there are usually not much rainfall-runoff data available that could be used to estimate the parameters through model calibration or optimization. Selection of a loss method has been based on a balance among model complexity, data availability, readiness of estimating loss parameters, maturity of a loss method, and ease of use. For example, the SCS Curve Number method has received extensive criticism because it does not lead to accurate reproduction of runoff hydrographs, the predicted infiltration rates are not in accordance with classical unsaturated flow theory, the method is applied to watersheds for which it was not calibrated, and the original calibration results are not available (USACE, 1994). However, it remains the most popular method for simulating rainfall hydrographs. This is probably because the method only has one parameter (the curve number). Various curve number tables were developed by the SCS and were well documented in SCS TR-55 (SCS, 1986), and the method is coded in almost every hydrologic program or modeling system (e.g., HEC-HMS, HEC-1, and WMS). Due to its popularity and easy of use, the SCS method was selected as one of the infiltration methods used on test watersheds, as described in Chapters 9 and 10.

Another example is the Initial and Uniform Loss method. Although it is an empirical method, it is popular because it is simple and only requires two parameters. In contrast, the Green and Ampt and Holtan Loss methods are not widely used although they are more physically based and most of the parameters can be estimated using soil data without model calibration. However, the methods are not easy to understand and they require more input parameters. The estimation of the parameter values requires spatial soils and land use data and the data processing can be tedious.

Given the availability of spatial data and recent advancements in computer technology in managing and processing the data, a different approach to selecting a loss method can be taken. More consideration should be given to the technical (or theoretical) basis of a method. Based on this approach, the Green and Ampt method was selected as one of the infiltration methods to be applied to the test watersheds. The Green and Ampt method is physically based and the model parameters can be estimated using available soils data. Literature on the relationship between soils data (e.g., NRCS STATSGO and SSURGO) and model parameters is available. This method has been applied to parts of the semi-arid and arid southwestern U.S. In Maricopa County, Arizona, the Green and Ampt method is the preferred method.

8.2.3 Channel Infiltration Losses

Tabulated CN values may not adequately account for infiltration losses in natural channels through larger subbasins; therefore, they could overestimate undeveloped watershed runoff in an arid environment. According to Reilly and Piechota (2005), infiltration losses through long, natural desert watercourses may justify lowering CN values by nearly 20 percent. For design purposes, however, no reduction is recommended at this time due to the limited research in this area.

8.2.4 Antecedent Moisture Condition

The application of the loss methods discussed above requires an estimate of the antecedent moisture condition (AMC) of the watershed surface cover and soils preceding a particular storm. In general, the heavier the antecedent rainfall, the greater the direct runoff that occurs from a given storm. For modeling purposes, the following three generalized definitions of AMC levels are often used:

- **AMC I**: Lowest runoff potential. The watershed soils are dry enough to allow satisfactory grading or cultivation to take place.
- **AMC II**: Moderate runoff potential; an average study condition.
- **AMC III**: Highest runoff potential. The watershed is practically saturated from antecedent rains.

Table 8-7 shows the use of AMC recommended by different counties (note: the AMC is also referred to as the antecedent runoff condition, or ARC). It is clear that the AMC depends on the watershed location, storm frequency and types, soil type, and land use. Considering the nature of storm types in California's desert regions, AMC-I is recommended for local thunderstorms and AMC-II is recommended for general storms.

Table 8-7. Summary of AMC Recommended by Different Counties.

County	**AMC**
Clark County, NV	AMC-II
Maricopa County, AZ for desert areas	AMC-I
Los Angeles County, CA	AMC-II
Riverside County, CA	AMC-II
San Diego County, CA for desert areas	Between AMC I and II (less than 35-year return period storms). AMC II (greater than or equal to 35-year return period storms)
San Bernardino County, CA	AMC I (2- and 5-year storms). AMC II (10-, 25-, and 50-year storms). AMC III (100-year storm).

8.3 Transformation

The transformation of precipitation excess to runoff is often accomplished either by the unit hydrograph model or the kinematic wave model. The unit hydrograph is based on the assumption that a watershed, in converting precipitation excess to runoff, acts as a linear, time-invariant system. The kinematic wave model is a conceptual model. It is based on mathematical simulation of surface runoff using the kinematic wave approximation of the unsteady flow equations for one-dimensional open channel flow (USACE, 1994). Table 8-8 shows a summary of the transformation methods recommended by different agencies. Each method that has been applied in the semi-arid and arid areas is discussed in the sections below.

Table 8-8. Summary of Transformation Methods Recommended by Counties/Agencies.

County/Agency	Method
Clark County, NV	SCS Unit Hydrograph or Kinematic Wave method
Los Angeles District, USACE	Synthetic Unit Hydrograph using an S-graph method
Maricopa County, AZ	Clark Unit Hydrograph (for urban watersheds ≤5 mi^2) Synthetic Unit Hydrograph using an S-Graph method (for major watercourses)
Riverside County, CA	Synthetic Unit Hydrograph using an S-Graph method
San Bernardino County, CA	Synthetic Unit Hydrograph using an S-Graph method
San Diego County, CA	SCS Unit Hydrograph

8.3.1 Unit Hydrograph Approach

A unit hydrograph (UH) for a drainage area is a curve showing the time distribution of runoff that would result at the concentration point from one inch of effective rainfall over the drainage area above that point.

The unit hydrograph method assumes that watershed discharge is related to the total volume of runoff, that the time factors that affect the unit hydrograph shape are invariant, and that watershed rainfall-runoff relationships are characterized by watershed area, slope, and shape factors.

A UH can be properly derived from observed rainfall and runoff. However, pairs of precipitation and streamflow data are often not available. Therefore, it is necessary to develop a synthetic UH on an ungaged watershed based on the properties of unit hydrographs developed from gaged watersheds. The S-graph method and parametric unit hydrographs are two approaches to develop a synthetic UH.

S-Graph

Because no two drainage areas have identical hydrologic characteristics, the runoff patterns from these areas are generally dissimilar and the time distribution of runoff may differ considerably. Therefore, direct transposition of the characteristic time distribution of runoff from drainage areas for which rainfall-runoff data are available to nearby areas for which data are not available is usually not a good idea. The S-graph method uses a basic time-runoff relationship for a watershed type in a form suitable for application to ungaged basins. An S-graph is a summation hydrograph of runoff that would result from the continuous generation of unit storm effective rainfall over the area (one-inch per hour continuously). The ordinate is expressed in percent of ultimate discharge, and the abscissa is expressed in percent of lag time. Ultimate discharge, which is the maximum discharge attainable for a given intensity, occurs when the rate of runoff on the summation hydrograph reaches the rate of effective rainfall. For a unit storm over a unit drainage area (one square mile) with a constant effective rainfall rate of one-inch per hour, the ultimate discharge is 645 cfs. Lag for a watershed is an empirical expression of the hydrologic characteristics of a watershed in terms of time. It is 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 percent of ultimate discharge. When the lags determined from summation hydrographs for several gaged watersheds are correlated to the hydrologic characteristics of the watersheds, an empirical relationship is usually apparent. This relationship can then be used to determine the lags for comparable ungaged drainage areas for which the hydrologic characteristics can be determined, and a unit hydrograph applicable to the ungaged watersheds can be easily derived.

As shown in Table 8-8, Riverside County, San Bernardino County, and Maricopa County (AZ) recommend the use of the S-graph method. These S-graphs are primarily based on S-graphs that were defined by the USACE, Los Angeles District, from a rather long and extensive history of analyses of floods in southern California and Arizona. Separate S-graphs were developed for the valley, foothill, mountain, and desert areas (Table 8-9).

Table 8-9. Type of S-Graphs Used by Different Counties.

County	**Number of S-graphs**	**Separate Regions**
Maricopa County, AZ	4	Phoenix Mountain, Phoenix Valley, Desert/Rangeland, and Agricultural
Riverside County, CA	4	Valley, Foothill, Mountain, and Desert.
San Bernardino County, CA	5	Valley (Developed), Valley (Undeveloped), Foothill, Mountain, and Desert

Clark Unit Hydrograph

The Clark method is a conceptual model. It accounts for translation and attenuation of overland and channel flow. It uses a linear reservoir model to solve the continuity equation. The linear reservoir represents the aggregated impacts of all watershed storage. In addition to this lumped model of storage, the Clark model accounts for the time required for water to move to the watershed outlet. The water is routed from remote points to the linear reservoir at the outlet with delay (translation), but without attenuation. Maricopa County (AZ) is one of the few counties that specifies use of the Clark unit hydrograph. It is the preferred procedure for urban watersheds in Maricopa County smaller than 5 to 10 square miles, while S-graphs must be used for all "major watercourses" (Maricopa County, 2003).

SCS Unit Hydrograph

The SCS dimensionless unit hydrograph is based on averages of unit hydrographs derived from gaged rainfall and runoff for a large number of small rural basins throughout the U.S. The definition of the SCS unit hydrograph normally only requires one parameter, which is lag, defined as the time from the centroid of precipitation excess to the time of the peak of the unit hydrograph. For ungaged watersheds, the SCS suggests that the unit hydrograph lag time, t_{lag}, may be related to time of concentration, t_c, through the following relation:

$$t_{lag} = 0.6\, t_c \tag{7.1}$$

The time of concentration is the sum of travel time through sheet flow, shallow flow, and channel segments.

Time of Concentration/Lag Time

The application of the unit hydrograph methods discussed requires the estimation of either the time of concentration, t_c, or lag time. The definition of lag in the SCS unit hydrograph is different from the lag time in the S-graph unit hydrograph. Lag in the SCS unit hydrograph is defined as the time from the center of mass of rainfall excess to the peak of the unit hydrograph. Table 8-10 summarizes the methods for estimating the lag or time of concentration. Many counties use the following general relationship for S-graph lag as a function of watershed characteristics:

$$Lag = c\left(\frac{LL_{ca}}{S^{0.5}}\right)^m \tag{7.2}$$

where:

Lag = basin lag, in hours,

L = length of the longest watercourse, in miles,

L_{ca} = length along the watercourse from the outlet to a point opposite the centroid, in miles,

S = watercourse slope, in feet per mile,

C = coefficient, and

m = exponent.

Table 8-10. Summary of Methods for Estimating Time of Concentration and Lag.

County	Time of Concentration/ Lag Time	Method
Clark County	SCS UH Lag	For small drainage basins (< 1 mi^2), Equation 7.1. For larger drainage basins (> 1 mi^2), Equation 7.2 with m=0.33 and C=20K_n (USBR, 1989). K_n is the roughness factor based on roughness factor analysis by USACE (1982) and USBR (1989).
Maricopa County	Clark UH t_c S-graph UH Lag	Papadakis and Kazan (1987) equation. Equation 7.2 with m=0.38 and C=24K_n (USACE, 1982).
Riverside County	S-graph UH Lag	Equation 7.2 with m=0.38 and C=24K_n (USACE, 1962).
San Bernardino County	S-graph UH Lag	For small drainage basins (< 1 mi^2), *Lag* = 0.8 t_c. For larger drainage basins (> 1 mi^2), Equation 7.2 with m=0.38 and C=24K_n.
San Diego County	SCS UH t_c	S-graph *Lag* = 0.8 t_c with Equation 7.2 for graph *Lag* (m=0.38 and C=24K_n , USACE, 1976).

8.3.2 Kinematic Wave Approach

The kinematic wave method is a quasi-physically based overland and channel routing procedure, in which model parameters can be chosen directly through the use of topographic maps, photographs, land use, and soils information. This method is considered a physically based procedure because it uses principles of energy to model the flow process. The method is not completely physically based, however, because several approximations are made in solving the equations. The method takes a spatially distributed view of the subbasin rather than a lumped view, like the unit hydrograph approach. The distributed feature allows the model to capture the different responses from both pervious and impervious areas in a single urban subbasin. The kinematic wave technique produces a nonlinear response to rainfall excess as opposed to the linear response of the unit hydrograph.

8.3.3 Method Selection

Similar to the selection of a rainfall loss method, the choice of a transformation method needs to consider primarily the availability of data to estimate the parameters or to calibrate the model and the appropriateness of the assumptions inherent in each method. Table 8-11 shows the advantages and disadvantages for each method. The use of the kinematic wave method is primarily for small basins (less than 1 square mile) in order to take advantage of its sound theoretical basis. For larger watersheds, it is difficult to implement (Ponce, 1991). For this reason, use of the kinematic wave method is not recommended. The S-graphs used by San Bernardino County, Riverside County, and Maricopa County are based on flood data in southern California and Arizona. They will be used in the southern part of the study areas (Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert). However, they may not be applicable to the northern regions (Owens Valley/Mono Lake and Northern Basin and Range). Other regional synthetic unit hydrographs, such as those developed by USBR (1987) are recommended for the northern regions.

8.4 Channel Routing

Channel routing is a process used to predict the temporal and spatial variation of a flood hydrograph as it moves through a river reach. The effects of storage and flow resistance within a river reach are reflected by changes in hydrograph shape and timing as the flood wave moves from upstream to downstream. Table 8-12 summarizes the channel routing methods recommended by different agencies. The four commonly used methods are the kinematic wave routing, Modified Puls routing, Muskingum routing, and Muskingum-Cunge routing. The advantages and disadvantages for each method are described in Table 8-13. Table 8-14 provides guidance for selecting an appropriate routing method (HEC, 2000). The Muskingum-Cunge routing method can handle a wide range of flow conditions with the exception of significant backwater. The Modified Puls routing can model backwater effects. The kinematic wave routing method is often applied in urban areas with well defined channels.

Table 8-11. Pros and Cons of Transformation Methods.

Method	**Pros**	**Cons**
S-Graph Unit Hydrograph	• Regional relationships based on observed data • Relies on only one parameter for a given S-graph, which can be estimated using basin characteristics.	• The application is normally limited to regions with watershed characteristics similar to these used to develop the lag time relationship.
Clark Unit Hydrograph	• A conceptual model. • With two parameters, there is substantial flexibility for fitting a wide variety of runoff responses. • Can incorporate effects of basin shape and timing factors through use of a time-area relation.	• Not widely used in desert areas. • Not much experience and data on parameter estimation.
SCS Unit Hydrograph	• Simple. • Relies on only one parameter. • Features readily grasped and reasonable well-documented inputs. • Well established method, widely accepted for use in U.S. and abroad.	• An empirical model. • Developed with data from small agricultural watersheds in U.S., so applicability elsewhere is uncertain. • Use of a one-parameter unit hydrograph can be very limiting with respect to the ability to fit the runoff response characteristics of a basin. • Only generates a single-peaked hydrograph.
Kinematic Wave method	• A conceptual model. • Spatially distributed. • Physically-based parameters.	• The use of kinematic wave method for main channels and large collectors should be limited to urban areas or moderately sloping channels as attenuation is not represented. • The use is primarily for small catchments (less than 1 square mile). For large watershed size, it is difficult to implement (Ponce, 1991).

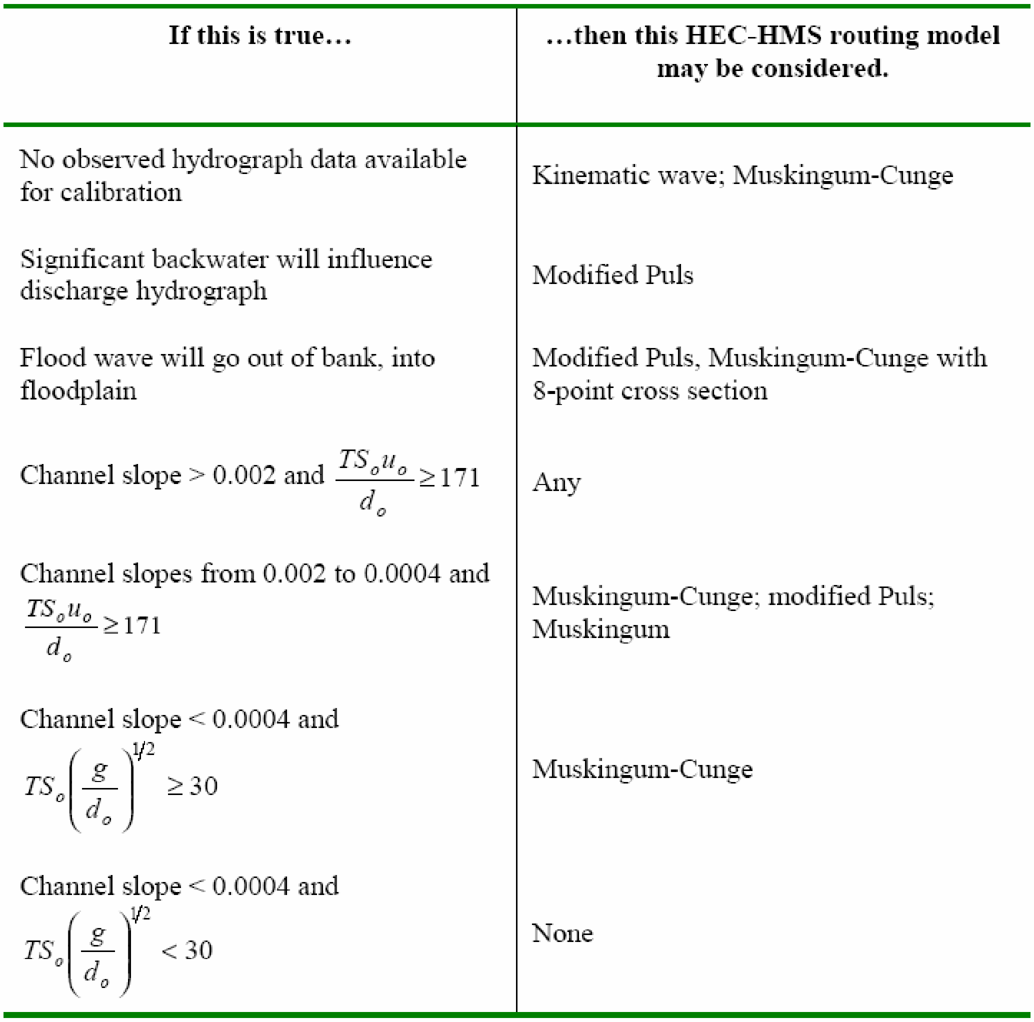
Table 8-12. Summary of Channel Routing Methods Recommended by Different Agencies.

County/Agency	Method
Clark County, NV	Kinematic Wave (for well-defined channels, such as trapezoidal or rectangular channels) Muskingum-Cunge (for channels that can be defined by cross section with limited points) Muskingum (for poorly-defined channels)
Maricopa County, AZ	Modified Puls Kinematic Wave Muskingum Muskingum-Cunge
Los Angeles County, CA	Modified Puls
Los Angeles District, USACE (1988)	Muskingum Modified Puls (for reservoir routing)
Riverside County, CA	Successive Average-Lag and Muskingum (for channel routing) Modified Puls (for reservoir routing)
San Bernardino County, CA	Modified Puls (for reservoir routing) Convex method (for streamflow routing)

Table 8-13. Pros and Cons of Channel Routing Methods.

Routing Method	Pros	Cons
Kinematic Wave	• A conceptual model assuming a uniform flow condition. • In general, works best for steep (10 ft/mile or greater), well defined channels. • It is often applied in urban areas because the routing reaches are generally short and well-defined.	• Cannot handle hydrograph attenuation, significant overbank storage, and backwater effects.
Modified Puls	• Known as storage routing or level-pool routing • Can handle backwater effects through the storage-discharge relationship.	• Need to use hydraulic model to define the required storage-outflow relationship.
Muskingum	• Directly accommodates the looped relationship between storage and outflow. • A linear routing technique that uses coefficients to account for hydrograph timing and diffusion.	• The coefficients cannot be used to model a range of floods that may remain in bank or go out of bank. Therefore, not applicable to significant overbank flows.
Muskingum-Cunge	• A nonlinear coefficient method that accounts for hydrograph diffusion based on physical channel properties and the inflowing hydrograph. • The parameters are physically based. • Has been shown to compare well against the full unsteady flow equations over a wide range of flow conditions.	• It cannot account for backwater effects. • Not very applicable for routing a very rapidly rising hydrograph through a flat channel.

Table 8-14. Guidelines for Selecting Routing Model (source: HEC, 2000).



If this is true…	…then this HEC-HMS routing model may be considered.
No observed hydrograph data available for calibration	Kinematic wave; Muskingum-Cunge
Significant backwater will influence discharge hydrograph	Modified Puls
Flood wave will go out of bank, into floodplain	Modified Puls, Muskingum-Cunge with 8-point cross section
Channel slope > 0.002 and $\frac{TS_o u_o}{d_o} \geq 171$	Any
Channel slopes from 0.002 to 0.0004 and $\frac{TS_o u_o}{d_o} \geq 171$	Muskingum-Cunge; modified Puls; Muskingum
Channel slope < 0.0004 and $TS_o \left(\frac{g}{d_o}\right)^{1/2} \geq 30$	Muskingum-Cunge
Channel slope < 0.0004 and $TS_o \left(\frac{g}{d_o}\right)^{1/2} < 30$	None

Note: T = hydrograph duration

u_o = reference mean velocity

d_o = reference flow depth

S_o = channel slope

9 RAINFALL-RUNOFF SIMULATION: TEST WATERSHEDS AND STUDY APPROACH

Seven watersheds were selected to test the rainfall-runoff methods believed to be the most applicable to California's desert regions. The selection of test watersheds, the available watershed data, and the study approach are described in this chapter.

9.1 Selection Criteria

Test watersheds for each desert region were selected based on the following criteria:

- Availability of nearby peak streamflow gage(s) and hourly precipitation station(s) with overlapping periods of record.
- One or more peak streamflow events occurring during the overlapping period of record.
- Preference was given to watersheds: (1) where a precipitation gage was located in the upper portion of the watershed, and (2) where the creek/wash can impact a road or highway.

9.2 Selected Test Watersheds

The selected test watersheds are listed in Table 9-1. The watershed areas range from 2.1 to 34.2 mi^2. Watershed locations are shown in Figure 9-1.

Table 9-1. Test Watersheds.

Desert Region	Watershed Name	Watershed Area (mi^2)
Region 1 – Colorado Desert	Borrego Palm Canyon	21.8
Region 2 – Sonoran Desert	Monument Wash	4.3
Region 3 – Antelope Valley	Big Rock Wash	34.2
Region 4 – Mojave Desert (Site 1)	West Fork Mojave River	3.2
Region 4 – Mojave Desert (Site 2)	Fortynine Palms Creek	8.5
Region 5 – Owens Valley/Mono Lake	Independence Creek	18.1
Region 6 – Northern Basin and Range	Mill Creek	2.1

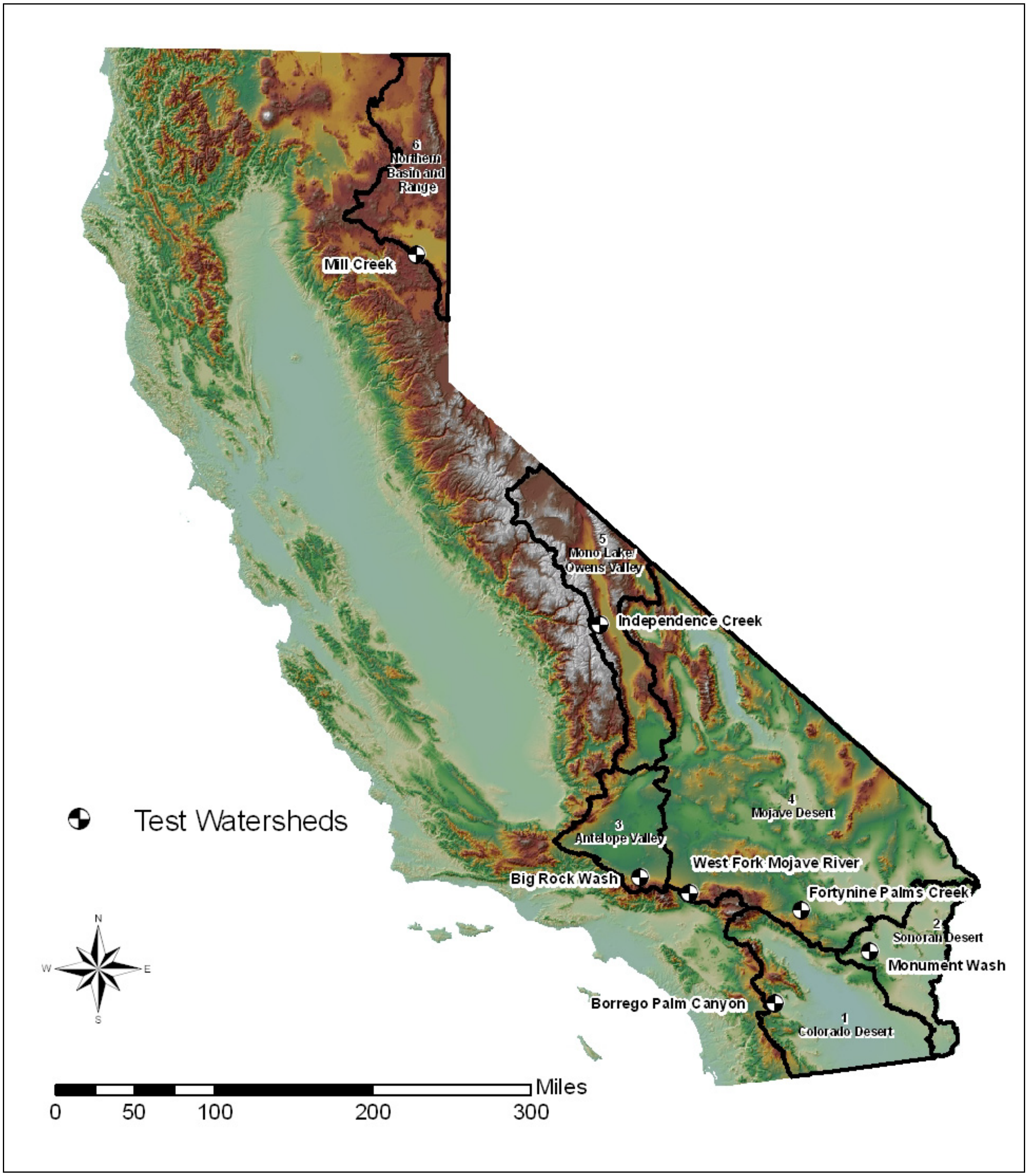


Figure 9-1. Test Watersheds.

9.3 Watershed Data

Data used in selecting the test watersheds and for creating the hydrologic models are described below. Appendix E provides a list of online sources for the watershed data.

9.3.1 Peak Streamflow

The locations of peak streamflow gages were obtained from the USGS, Los Angeles County Department of Public Works, City of Los Angeles Department of Water and Power (DWP), and San Bernardino County Flood Control District. The figures in Appendix C show where peak streamflow gages are located (or were located for discontinued gages) in each of the desert regions.

The USGS was contacted to obtain more detailed (e.g., hourly or 15-minute) gage data at selected gages for flood events; however, these data were not available in most cases. The USGS could not provide hourly or 15-minute data for events occurring prior to Water Year 1988. The only watersheds for which detailed gage data were provided were Big Rock Wash the in Antelope Valley (peak event in 2005) and West Fork Mojave River in the Mojave Desert (peak event in 1998).

9.3.2 Precipitation

The locations of hourly precipitation stations were obtained from the National Climatic Data Center (NCDC), Los Angeles County Department of Public Works, San Bernardino County Flood Control District, and the San Diego County Department of Public Works. In addition, the hourly stations used in the development of NOAA Atlas 14 were identified. The figures in Appendix C show where hourly precipitation stations are located in each of the desert regions.

Hourly data (or 15-minute data, where available) were obtained for gages in and around the test watersheds, for the selected rainfall events.

9.3.3 Topography

The USGS Seamless Digital Elevation Model (DEM) was used as the base topographic data for delineating watershed and subbasin boundaries.

9.3.4 Soils

Soils data were obtained from the USDA Natural Resources Conservation Service (NRCS) Soil Data Mart. STATSGO soils data are available digitally and cover the entire state. SSURGO soils data are significantly more detailed than STATSGO. SSURGO data were used where available; however, SSURGO data were only available for the Big Rock Wash, West Fork Mojave River, and Mill Creek watersheds and a portion of the Borrego Palm Canyon watershed.

9.3.5 Vegetation/Land-use

Vegetation/land-use data were obtained from the Gap Analysis Project at the University of California, Santa Barbara (Davis *et al.*, 1998). The name of the project and its resulting data derives from its use in defining habitat to locate gaps in the conservation reserve system.

9.4 Study Approach

The HEC-HMS (Hydrologic Modeling System) computer program, Version 3.1.0, was used for rainfall-runoff simulation of the test watersheds (Hydrologic Engineering Center, 2006b).

9.4.1 Actual Storm Events

For each test watershed, actual storm events (1-2 per watershed) were modeled and the results were compared to stream gage data. All test watersheds were treated as ungaged basins and parameters were selected based on available data. While a comparison was made to known discharges, true "calibration" of parameters was not performed because calibration would not be possible for the ungaged basins that are typically studied in desert areas.

The selection of a modeling approach for each rainfall-runoff component focused on the theoretical basis of the method, as well as its practical application, and this selection process was described in Chapter 8. An approach that is more physically-based with parameters that can be readily estimated with available data – without requiring extensive calibration – greatly increases the method's applicability to any ungaged watersheds.

Table 9-2 presents the rainfall depth-area reduction methods that were selected based on location and Figure 9-2 provides a graphical comparison of the depth-area reduction methods.

Table 9-3 lists the infiltration methods that were tested. For the SCS Curve Number method, Table 9-4 provides a comparison of the habitat types from Gap Analysis Project vegetation/land-use data and the corresponding CN values.

Table 9-5 lists the transformation methods that were tested, and Figure 9-3 shows a comparison of the S-Graphs used in the study. For graphical purposes, the percent lag time was cut off at 800%; however, the San Bernardino County Mountain S-Graph reaches 100% total discharge at 1300% of lag time.

The most appropriate channel routing method was selected for each test watershed based on the channel characteristics, available data, and the guidance described in Section 8.4. Multiple channel routing methods were not compared for a given test watershed.

Table 9-2. Rainfall Depth-Area Reduction Methods.

Rainfall Depth-Area Reduction	**Desert Regions**
HYDRO-40	Colorado Desert, Sonoran Desert, Antelope Valley, Mojave Desert
NOAA Atlas 2	Owens Valley/Mono Lake, Northern Basin and Range

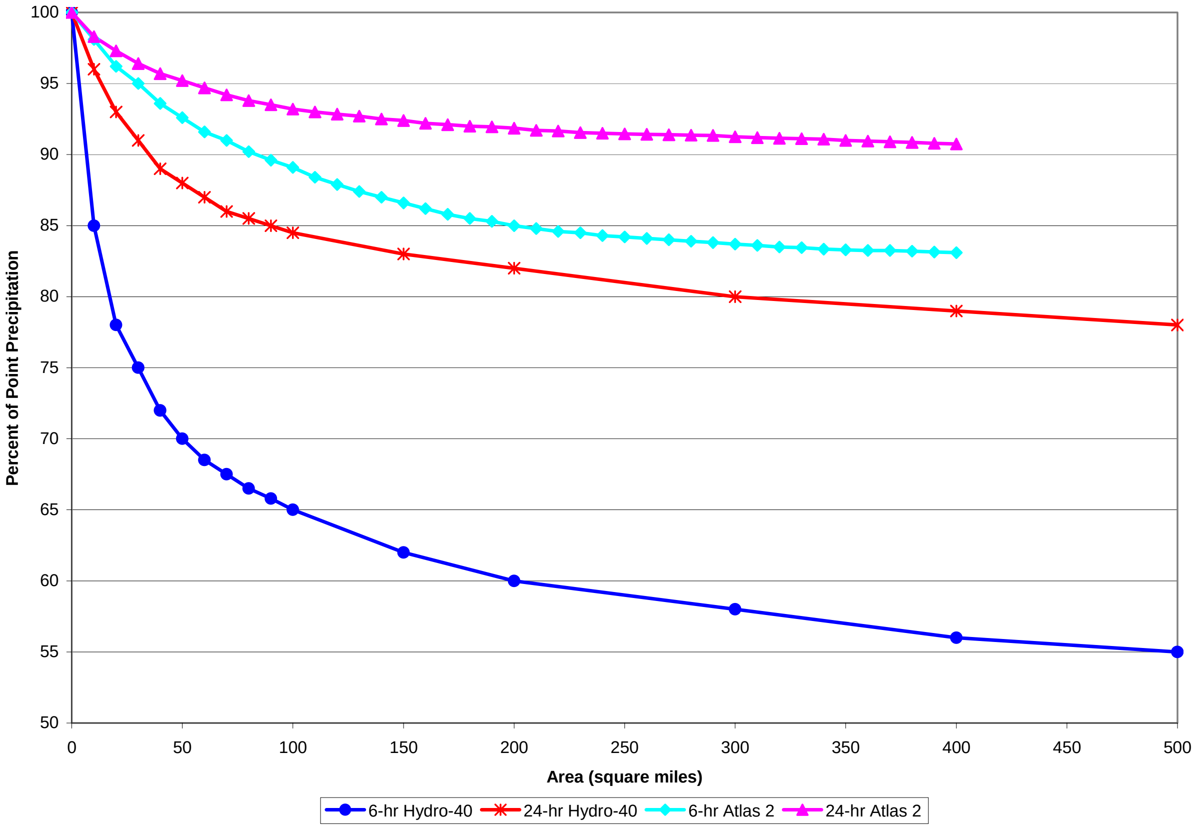


Figure 9-2. Depth-Area Reduction Method Comparison.

Table 9-3. Infiltration Methods Tested.

Infiltration Method	**Desert Regions**
SCS Curve Number	All regions
Green and Ampt	Colorado Desert, Sonoran Desert, Antelope Valley, Mojave Desert

Table 9-4. SCS Curve Numbers (AMC II) for Fair Hydrologic Conditions.

Habitat Classification in GAP Vegetation Data (WHR)[1]	**Curve Number Cover Description**[2]	**Soil Group**			
		A	**B**	**C**	**D**
Alkali Desert Scrub (ASC)	Desert Shrub[3]	55	72	81	86
Desert Scrub (DSC)	Desert Shrub[3]	55	72	81	86
Desert Succulent Scrub (DSS)	Desert Shrub[3]	55	72	81	86
Desert Wash (DSW)	Desert Shrub[3]	55	72	81	86
Palm Oasis (POS)	Woods-grass combination	43	65	76	82
Chamise-Redshank Chaparral (CRC)	Chaparral, Narrowleaf (Chamise and Redshank)	55	72	81	86
Mixed Chaparral (MCH)	Chaparral, Broadleaf (Manzanita, ceanothous and scrub oak)	40	63	75	81
Montane Chaparral (MCP)	Chaparral, Broadleaf (Manzanita, ceanothous and scrub oak)	40	63	75	81
Alpine Dwarf Shrub (ADS)	Brush – brush-weed-grass mixture with brush the major element	35	56	70	77
Bitterbrush (BBR)	Sagebrush with grass understory	51[4]	51	63	70
Low Sage (LSG)	Sagebrush with grass understory	51[4]	51	63	70
Sagebrush (SGB)	Sagebrush with grass understory	51[4]	51	63	70
Coastal Scrub (CSC)	Open Brush (soft wood shrubs - buckwheat, sage, etc.)	46	66	77	83
Juniper (JUN)	Pinyon-juniper (pinyon, juniper, or both; grass understory)	58[4]	58	73	80
Pinyon-Juniper (PJN)	Pinyon-juniper (pinyon, juniper, or both; grass understory)	58[4]	58	73	80
Closed-Cone Pine Cypress (CPC)	Woods[5]	36	60	73	79
Jeffrey Pine (JPN)	Woods[5]	36	60	73	79
Lodgepole Pine (LPN)	Woods[5]	36	60	73	79
Montane Hardwood-Conifer (MHC)	Woods[5]	36	60	73	79
Montane Hardwood (MHW)	Woods[5]	36	60	73	79
Ponderosa Pine (PPN)	Woods[5]	36	60	73	79
Subalpine Conifer (SCN)	Woods[5]	36	60	73	79
Sierran Mixed Conifer (SMC)	Woods[5]	36	60	73	79
Annual Grassland (AGS)	Pasture, grassland, or range-continuous forage for grazing	49	69	79	84
Barren (BAR)	Barren (Rockland, eroded and graded land)	78	86	91	93

1. WHR is the Wildlife Habitat Relationship code from the Gap Analysis Project vegetation/land-use data (Davis *et al.*, 1998).
2. Habitat Classifications correspond to WHR codes. Cover Descriptions and Curve Numbers are from SCS (1986) and San Bernardino County (1986).
3. Major plants for desert shrubs include saltbrush, greasewood, creosotebush, blackbush, bursage, palo verde, mesquite, and cactus.
4. Curve numbers for Soil Group A have not been developed. CN value for Soil Group B used.
5. For Woods, Curve Numbers for “Good” hydrologic conditions are 30, 55, 70, and 77 for Groups A through D, respectively.

Table 9-5. Transformation Methods Tested.

Transformation Method	Desert Regions
S-Graph – San Bernardino County "Desert"	Colorado Desert, Sonoran Desert, Antelope Valley, Mojave Desert
S-Graph – San Bernardino County "Mountain"	Antelope Valley, Mojave Desert
S-Graph – Maricopa County "Desert/Rangeland"	Sonoran Desert, Mojave Desert
S-Graph – USBR (1987)	Owens Valley/Mono Lake, Northern Basin and Range

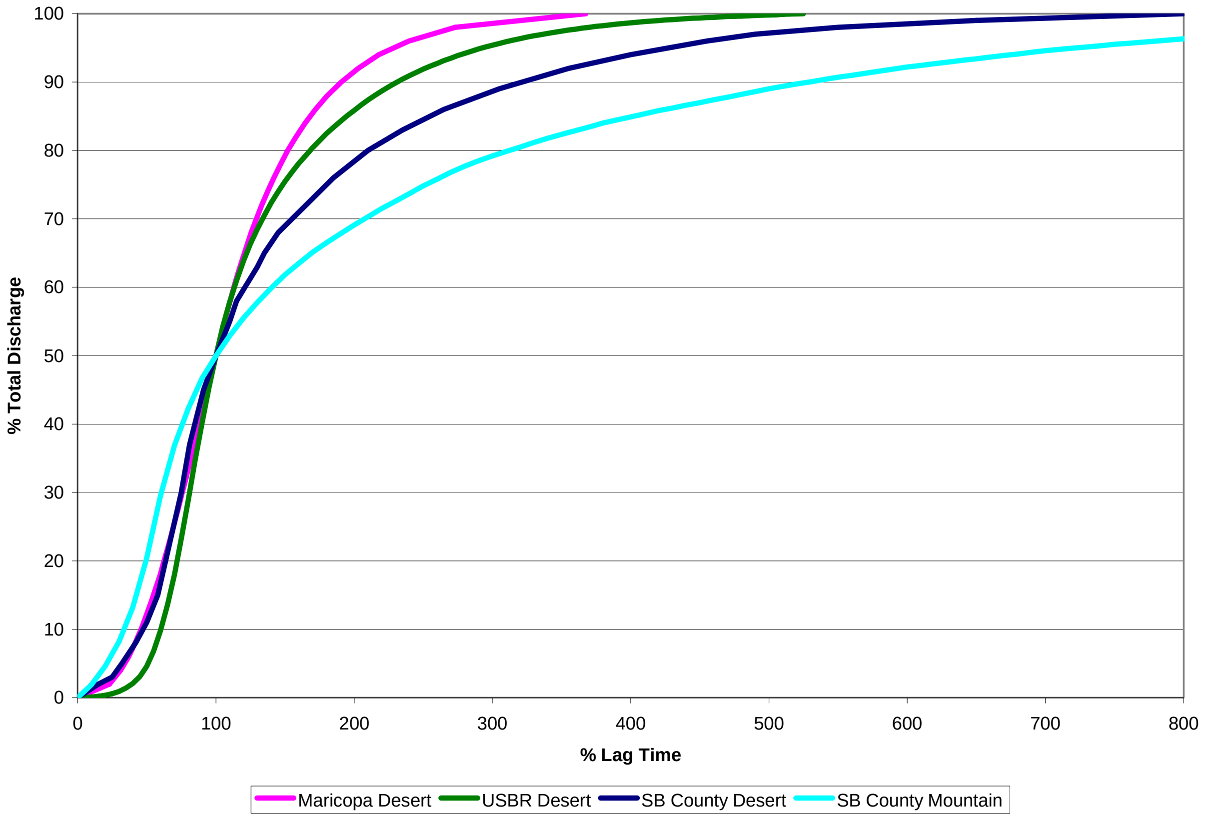


Figure 9-3. S-Graph Comparison.

9.4.2 Synthetic Storm Events

After the model parameters were selected and recorded rainfall-runoff events were simulated, each hydrologic model was then used to simulate a synthetic design storm to compute the 100-year peak discharge. The storm duration, antecedent moisture condition, and temporal storm distribution used for the test watersheds are listed in Table 9-6. The Antecedent Moisture Conditions listed in this table were also used in selecting Curve Numbers when modeling actual storm events. Figure 9-4 shows a comparison of the 6-hour and 24-hour temporal distributions.

The peak discharges computed using the synthetic storm events were compared with those computed using applicable regional regression equations, and with those computed by flood-frequency analysis using the HEC-SSP program (for stream gages with adequate periods of record).

Table 9-6. Storm Durations, Antecedent Moisture Conditions, and Temporal Distributions Tested.

Storm Duration, AMC, and Temporal Distribution	Desert Regions
6-hour duration with AMC-I, NOAA Atlas 14 Convective Storm	Colorado Desert, Sonoran Desert, Antelope Valley, Mojave Desert (for watersheds ≤ 100 mi^2)
24-hour duration with AMC-II, NOAA Atlas 14 General Storm	Colorado Desert, Sonoran Desert, Antelope Valley, Mojave Desert (for watersheds > 20 mi^2) Owens Valley/Mono Lake, Northern Basin and Range

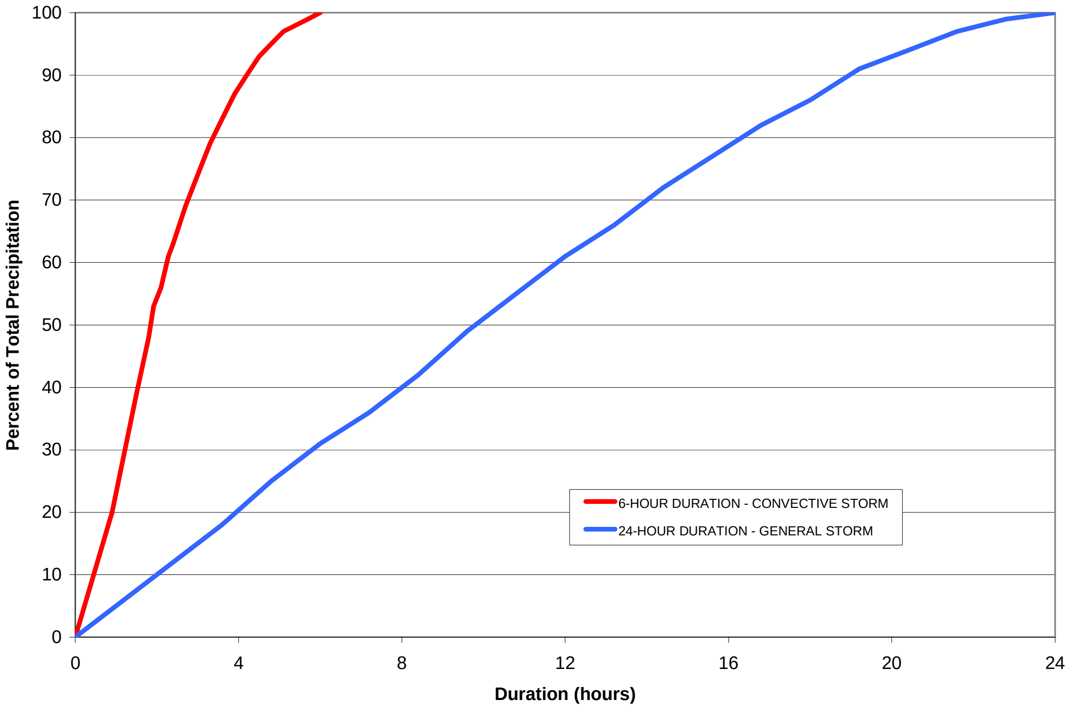


Figure 9-4. Temporal Distribution Comparison – NOAA Atlas 14.

10 RAINFALL-RUNOFF SIMULATION: RESULTS AND DISCUSSION

Included in this chapter are descriptions of each of the test watersheds, rainfall-runoff model results, and a discussion of what the modeling efforts yielded in terms of the most appropriate hydrologic methods and parameters for California's desert regions. Finally, a hydrology flow chart is presented, which includes guidance for not only hydrologic modeling, but also incorporates findings from the flood frequency and regional regression chapters.

The approach taken in the rainfall-runoff simulation was to treat the test watersheds as if they were ungaged, with the selection of appropriate model parameters based on readily available data for the watershed rather than performing true model calibration. Instead of calibration, the applicability of the hydrologic methods and parameters was validated by comparing rainfall-runoff computed flows to either observed values or those computed by flood-frequency analysis or using the new regional regression equations.

10.1 Borrego Palm Canyon (Colorado Desert)

10.1.1 Watershed Description

Borrego Palm Canyon watershed has an area of 21.8 square miles at USGS stream gage 5810. While it does not have a direct impact on any state highways, it is representative of the watersheds in this desert region. It has over 27 years of overlapping data with several peaks occurring during this period.

Table 10-1 provides a summary of the precipitation and peak streamflow gages for the Borrego Palm Canyon watershed and Figure 10-1 provides the locations of the gages. The Borrego Palm Canyon precipitation gage is located just below the stream gage. The precipitation gage at Henshaw Dam is located to the west of the watershed divide, but should provide a better precipitation pattern for the upper portion of the watershed.

Table 10-1. Gages for Borrego Palm Canyon.

Type	Station Name	Start Year of Data	End Year of Data	Elevation at Gaging Station (ft)	Source
Precipitation	Borrego Palm Canyon	1969	Present	~1,000	San Diego County
Precipitation	Henshaw Dam	1942	Present	2,700	NCDC Hourly
Streamflow	Borrego Palm Cyn nr Borrego Springs (10255810)	1951	2004	1,200	USGS

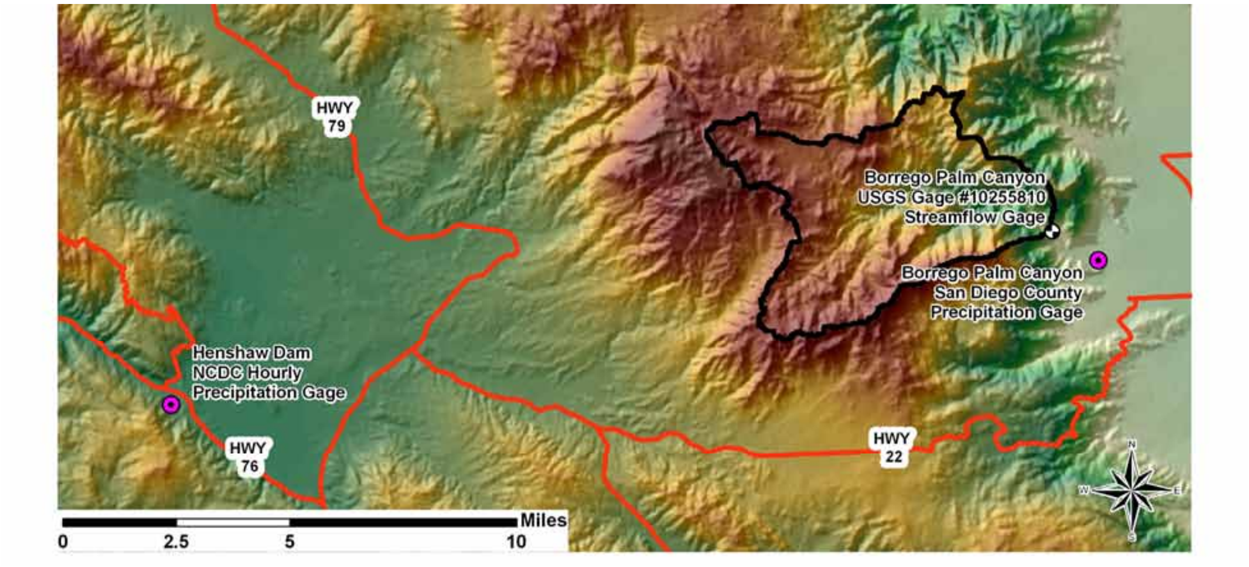


Figure 10-1. Gage Locations for Borrego Palm Canyon.

10.1.2 Results – Recorded Rainfall

One rainfall/flood event was modeled for the Borrego Palm Canyon watershed: August 15, 1977. Precipitation data from the Henshaw Dam gage were used for the entire watershed because of the uncertain validity of data from the Borrego Palm Canyon precipitation gage for this event. This peak is the third largest event in the period of record. The two larger peaks occurred in 2003 and 1955, both years following a large wildfire in the watershed. Due to the disruption of natural basin characteristics, these peaks were not considered the best choices for modeling and the 1977 peak was used.

Table 10-2 provides a comparison of computed peak discharges from the rainfall-runoff model and the measured peak discharge for the August 15, 1977 event. The last column represents the percent difference between each rainfall-runoff model method and the USGS measured peak flow. The AMC I Curve Number method along with the San Bernardino Desert S-Graph provided the best result for this event because the AMC II Curve Number method results in too much runoff and the Green and Ampt Method results in too much infiltration loss.

Table 10-2. Borrego Palm Canyon – August 15, 1977 Flood Event.

Source	Method(s)		Peak Discharge (cfs)	% Difference vs. USGS
USGS Stream Gage	Measured Peak		2,160	n/a
Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I)	San Bern. Co. Desert S-Graph	1,760	-19%
	Curve Number (AMC II)	San Bern. Co. Desert S-Graph	3,530	63%
	Green and Ampt	San Bern. Co. Desert S-Graph	1,160	-46%

10.1.3 Results – 100-year Event

The 100-year, 6-hour Convective Storm and 100-year, 24-hour General Storm were simulated in HEC-HMS for Borrego Palm Canyon since its drainage area is greater than 20 square miles (see Table 9-6). Rainfall depths for each subbasin were determined based on digital NOAA Atlas 14 maps. These rainfall depths were then reduced using the HYDRO-40 rainfall depth-area reduction method as described in Sections 8.1.4 and 9.4.1. Figure 9-2 illustrates the relationship between the watershed area and the depth-area reduction percentage. Once the depth-area reduction percentage was determined, it was applied to each subbasin. The following reduction percentages were applied to the rainfall depths: 92.6% for the 24-hour storm depths and 77.5% for 6-hour storm depths. The San Bernardino Desert S-Graph was used for all 100-year runs.

Table 10-3 provides a summary of the computed 100-year peak discharges for Borrego Palm Canyon. Large wildfires occurred in the Borrego Palm Canyon watershed in 1954 and 2002. The following years, 1955 and 2003, recorded two of the largest peaks in the 48-year period of record at the USGS gage. Due to the effects of the fires, the characteristics of the watershed were likely changed from its natural state, i.e., less land cover and fire-induced water repellency of the soil, resulting in higher runoff values. Since these two peaks are included in the flood-frequency analysis, the computed 100-year peak discharge of 6,060 cfs might be too high for comparison purposes. A "natural" 100-year peak discharge was calculated by not including the post-fire peaks in 1955 and 2003.

The AMC I Curve Number method with the 6-hour Convective Storm provided the best results for the 100-year discharge. The AMC II Curve Number method with the 24-hour General Storm provided a reasonable result, but the temporal distribution of the general storm resulted in a lower peak discharge. The Green and Ampt method overestimated the infiltration loss and resulted in peak discharges much lower than the computed FFA peak discharge for both the 6-hour Convective Storm and the 24-hour General Storm.

Table 10-3. Borrego Palm Canyon – Computed 100-year Flood Event.

Source	**Method(s)**		**100-yr Peak Discharge (cfs)**	**% Difference vs. USGS (No Post-Fire Events)**
USGS Stream Gage	Flood-frequency Analysis (All Events)		6,060	n/a
	Flood-frequency Analysis (No Post-Fire Events)		2,910	0%
Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I)	6-hr NOAA Atlas 14 Convective Storm	3,010	3%
	Curve Number (AMC II)	24-hr NOAA Atlas 14 General Storm	2,410	17%
	Green and Ampt	6-hr NOAA Atlas 14 Convective Storm	1,120	-62%
	Green and Ampt	24-hr NOAA Atlas 14 General Storm	140	-95%
Regional Regression	Equation 6.7 for Southern Desert Regions		4,280	47%

10.2 Monument Wash (Sonoran Desert)

10.2.1 Watershed Description

Monument Wash watershed has an area of 4.3 square miles at USGS stream gage #3750. It drains adjacent to Interstate 10, and has 13 years of overlapping data with one large peak occurring during this period. The precipitation gage is at a higher elevation than the stream gage and is located at Hayfield Lake approximately 15 miles to the west of the stream gage. The availability of data in the Sonoran Desert is extremely limited and therefore this was the best test watershed available.

Table 10-4 provides a summary of the precipitation and peak streamflow gages for the Monument Wash watershed and Figure 10-2 shows the locations of the gages.

Table 10-4. Gages for Monument Wash.

Type	Station Name	Start Year of Data	End Year of Data	Elevation at Gaging Station (ft)	Source
Precipitation	Hayfield Pump Plant	1933	Present	1,371	NCDC Hourly
Streamflow	Monument Wash nr Desert Center (10253750)	1960	1973	~900	USGS

Figure 10-2. Gage Locations for Monument Wash.

10.2.2 Results – Recorded Rainfall

One rainfall/flood event was modeled for the Monument Wash watershed: September 5, 1967. Precipitation data from the Hayfield Pump Plant were used for the entire watershed. The recorded USGS peak flow of 100 cfs is an estimate, but is the only peak event that occurred during the overlapping time period. There is some uncertainty in the watershed drainage patterns because there appears to be split flow that occurs during higher flood events. A visual assumption was made that the 2/3 of the flow remains in Monument Wash and 1/3 of the flow will split off to the east (Figure 10-3). It should be noted that this assumption is based on a recent aerial photo taken nearly 40 years after the modeled storm event. However, the split is assumed to have changed little over this time period.

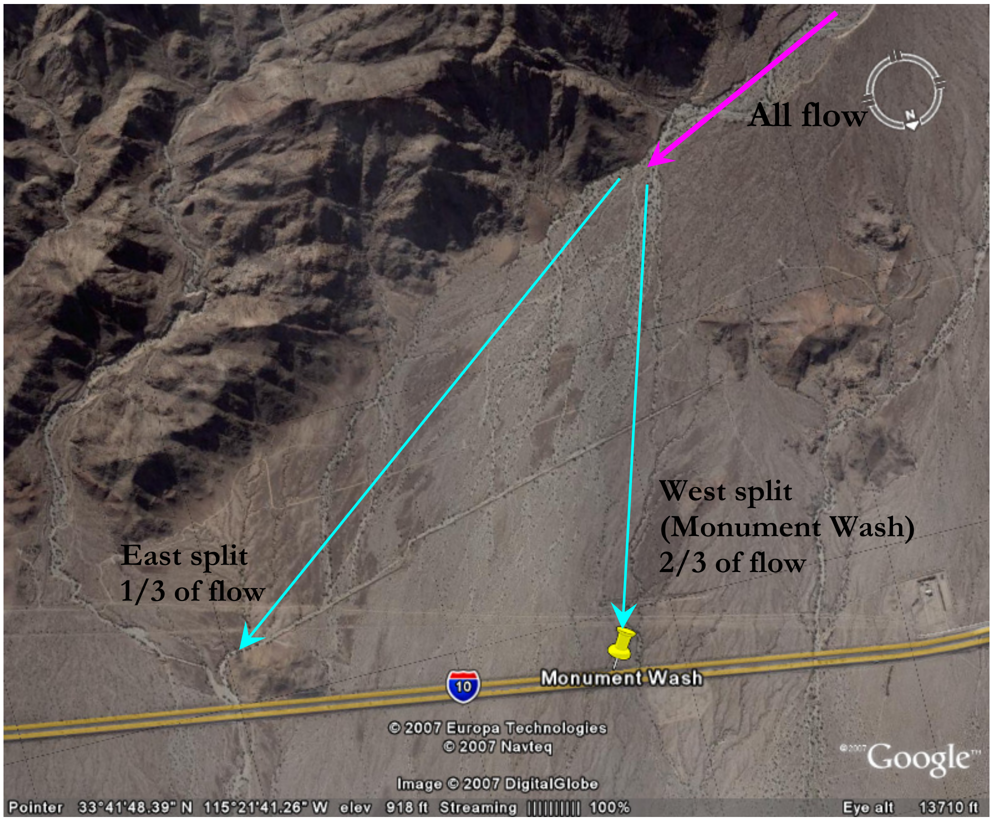


Figure 10-3. Assumed Flow Split for Monument Wash.

Table 10-5 provides a comparison of computed peak discharges from the rainfall-runoff model and the measured peak discharge for the September 5, 1967 event. The AMC I Curve Number method with both the San Bernardino County Desert S-Graph and the Maricopa County S-Graph provided reasonable results in comparison to the USGS estimated peak discharge. However, the AMC I Curve Number method with the San Bernardino County Desert S-Graph provided the best results for this event with only a 20% differential (after the assumed 2/3 flow split). The Green and Ampt method with both the San Bernardino and Maricopa County S-Graph resulted in a peak discharge value of zero. This method is over calculating the infiltration loss and therefore did not provide a reasonable answer.

Table 10-5. Monument Wash – September 5, 1967 Flood Event.

Source	Method(s)		Peak Discharge (cfs)	% Difference vs. USGS
USGS Stream Gage	Measured Peak		100[1]	n/a
Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I)	San Bernardino County S-Graph	180 (120)[2]	80% (20%)
	Green and Ampt	San Bernardino County S-Graph	0	-100%
	Curve Number (AMC I)	Maricopa County S-Graph	230 (150)	130% (50%)
	Green and Ampt	Maricopa County S-Graph	0	-100%

1. The USGS flow is listed as an estimate.
2. Values in parentheses are with the assumed 2/3 flow split.

10.2.3 Results – 100-year Event

The 100-year, 6-hour Convective Storm was simulated in HEC-HMS for Monument Wash, the 100-year, 24-hour General Storm was not simulated because the drainage area is less than 20 square miles. No rainfall depth-area reduction was applied because the drainage area is less than 9.6 square miles (NOAA Atlas 2 criteria).

Table 10-6 provides a summary of the computed 100-year peak discharges for Monument Wash. A flood-frequency analysis was not performed on the stream gage because there is uncertainty of flow split ratio that will occur during such a high flow event. Therefore, HEC-HMS computed peak discharges were compared to the value from new regional regression equations. No split flow adjustment was applied to any of these discharges. As with the recorded rainfall event, both the AMC I Curve Number method with the San Bernardino County Desert S-Graph and the Maricopa County S-Graph provided good results, and the Green and Ampt method overestimated the infiltration loss and resulted in a zero flow value. The best result for the 100-year event in comparison to the regional regression peak discharge is provided by the AMC I Curve Number method with the Maricopa County S-Graph.

Table 10-6. Monument Wash – Computed 100-year Flood Event.

Source	Method(s)		Peak Discharge (cfs)	% Difference vs. USGS
USGS Stream Gage	Flood-frequency Analysis		n/a[1]	n/a
Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I)	San Bernardino County S-Graph	1,300	n/a
	Green and Ampt	San Bernardino County S-Graph	0	n/a
	Curve Number (AMC I)	Maricopa County S-Graph	1,450	n/a
	Green and Ampt	Maricopa County S-Graph	0	n/a
Regional Regression	Equation 6.7 for Southern Desert Regions		1,470	n/a

1. A flood frequency analysis was not performed on the USGS gage because there is uncertainty in the ratio of the flow split during a high flow event.

10.3 Big Rock Wash (Antelope Valley)

10.3.1 Watershed Description

Big Rock Wash watershed has an area of 34.2 square miles at USGS stream gage #3630. The wash crosses under Highway 138 downstream of this stream gage. It only has 4 years of overlapping data, but two peaks occurred during this period. A second USGS stream gage (#3500) is located upstream of stream gage #3630 and has a drainage area of 23 square miles. It has 8 years of overlapping data. The Cedar Springs and Crystal Lake precipitation gages are located in upper elevations just south of the watershed divide, the Lewis Ranch precipitation gage is located to the west of the watershed at approximately the average basin elevation, and the Big Pines Rec precipitation gage is located to the east of the watershed in upper elevations.

Table 10-7 provides a summary of the precipitation and peak streamflow gages for the Big Rock Wash watershed and Figure 10-4 provides the locations of the gages.

Table 10-7. Gages for Big Rock Wash.

Type	Station Name	Start Year of Data	End Year of Data	Elevation at Gaging Station (ft)	Source
Precipitation	Lewis Ranch Precip	2001	Present	~4,600	LA County ALERT
Precipitation	Cedar Springs Precip	2001	Present	~7,000	LA County ALERT
Precipitation	Crystal Lake Precip	2001	Present	~5,400	LA County ALERT
Precipitation	Big Pines Rec Precip	1999	Present	~7,000	LA County ALERT
Streamflow	Big Rock Ck nr Valyermo (10263500)	1923	2005	4,050	USGS
Streamflow	Big Rock Ck ab Pallett Ck nr Valyermo (10263630)	2003	2005	3,555	USGS

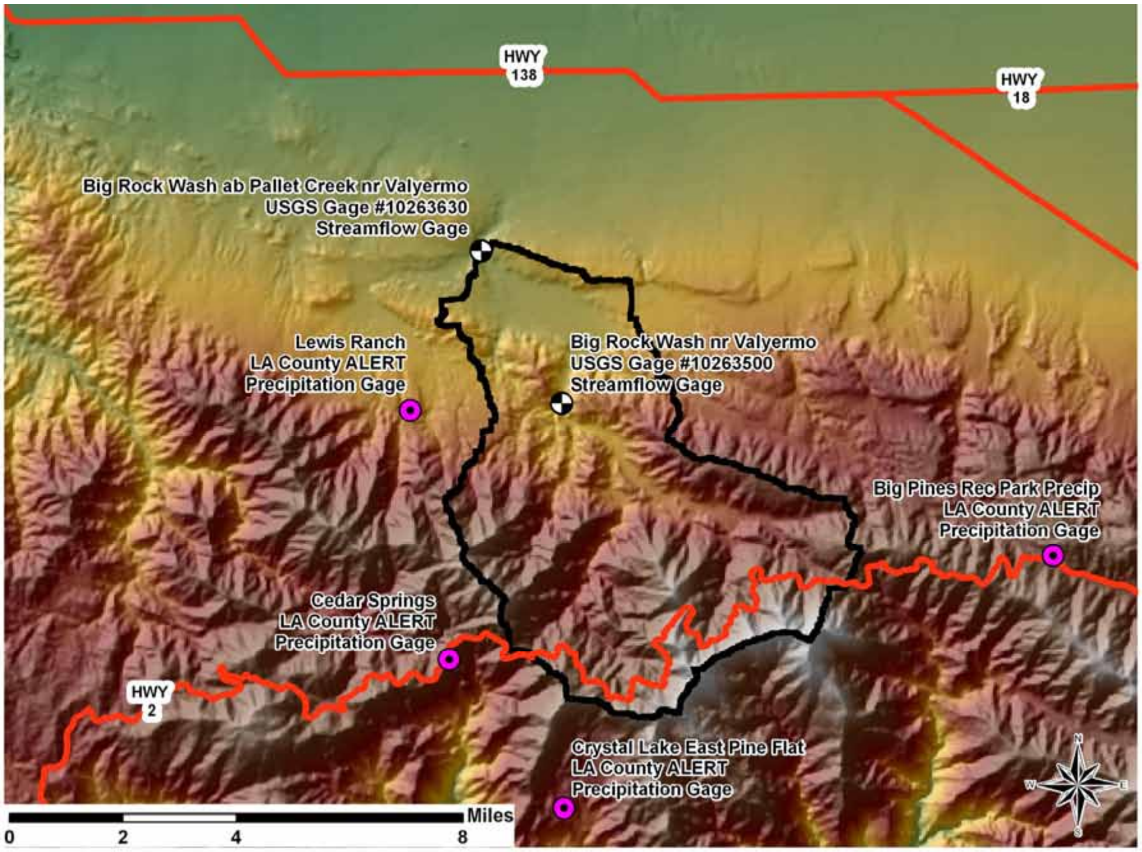


Figure 10-4. Gage Locations for Big Rock Wash.

10.3.2 Results – Recorded Rainfall

One rainfall/flood event was modeled for the Big Rock Wash watershed: January 9, 2005. Precipitation data from the Lewis Ranch gage were used for the entire watershed because of the uncertainty of the storm patterns in the higher elevations. Comparison of the total rainfall depths during the 2005 event revealed very high total precipitation values in the Cedar Springs (17.5") and Crystal Lake (22.1") gages, virtually no precipitation at Big Pines gage, and an average amount at the Lewis Ranch gage (7.2"). The storm event likely dumped a majority of the precipitation on the south side of the mountains at the Crystal Lake and Cedar Springs gage and these depths might not be representative of what actually fell within the Big Rock watershed. The 2005 event is the largest peak event in the overlapping period of record.

Table 10-8 provides a comparison of computed peak discharges from the rainfall-runoff model and the measured peak discharge for the January 9, 2005 event. Although the Green and Ampt method appears to provide the best results for this event, there is uncertainty related to the amount of precipitation that actually fell on the watershed during this event. The Green and Ampt method did not provide reasonable results for the other three watersheds; however, this is the largest watershed in the study so the Green and Ampt method may be more suitable for larger watersheds. The Green and Ampt method with the San Bernardino County Mountain S-Graph provides the best result.

The AMC II Curve Number method overestimates the peak discharge for the recorded event. The AMC I Curve Number method with San Bernardino County Desert and Mountain S-Graphs provided similar results for the peak discharge, but the Mountain S-Graph provided the better results of the two. Since the upper elevations of the Big Rock Wash watershed are higher than 9,000 feet, the San Bernardino County Mountain S-Graph is more suitable.

Table 10-8. Big Rock Wash – January 9, 2005 Flood Event.

	Source	Method(s)		Peak Discharge (cfs)	% Difference vs. USGS
Upstream Gage #10263500	USGS Stream Gage	Measured Peak at #10263500 (u/s gage)		2,550	n/a
	Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I)	San Bern. Co. Desert S-Graph	4,780	87%
		Curve Number (AMC I)	San Bern. Co. Mountain S-Graph	4,280	68%
		Curve Number (AMC II)	San Bern. Co. Mountain S-Graph	6,130	140%
		Green and Ampt	San Bern. Co. Desert S-Graph	3,660	44%
		Green and Ampt	San Bern. Co. Mountain S-Graph	3,060	20%
Downstream Gage #10263630	USGS Stream Gage	Measured Peak at #10263630 (d/s gage)		2,800[1]	n/a
	Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I)	San Bern. Co. Desert S-Graph	6,560	134%
		Curve Number (AMC I)	San Bern. Co. Mountain S-Graph	5,770	106%
		Curve Number (AMC II)	San Bern. Co. Mountain S-Graph	8,320	197%
		Green and Ampt	San Bern. Co. Desert S-Graph	3,780	35%
		Green and Ampt	San Bern. Co. Mountain S-Graph	3,050	9%

1. The USGS flow is listed as an estimate.

10.3.3 Results – 100-year Event

The 100-year, 6-hour Convective Storm and 100-year, 24-hour General Storm were simulated in HEC-HMS for Big Rock Wash since its drainage area is greater than 20 square miles. The HYDRO-40 rainfall depth-area reduction was applied to the rainfall depths: 90.1% for the 24-hour storm depths and 73.7% for 6-hour storm depths. From the recorded rainfall discharge comparisons, the assumption was made to compute the 100-year storm events using the Mountain S-Graph.

Table 10-9 provides a summary of the computed 100-year peak discharges for Big Rock Wash. At the upstream gage (#3500), the AMC II Curve Number method with the 24-hour General Storm provided the best results for the 100-year discharge in comparison with the Flood-frequency analysis discharge. This is an expected result as it would be more likely for a 24-hour General Storm to produce a peak in a large drainage area than a 6-hour Convective Storm because the Convective Storms typically do not affect an area the size of the watershed (23 square miles). A flood-frequency analysis was not performed on the downstream gage (#3630) because it only has nine years of record. The minimum period of record required to perform a flood-frequency analysis is ten years.

It would be expected that the AMC II Curve Number method with the 24-hour General Storm would provide the best results since the drainage area is even larger at this gage (34 square miles), therefore the General Storm would be more applicable than the Convective Storm. The Green and Ampt method under predicted the peak discharges for the 100-year flood event compared to the computed discharge from the flood-frequency analysis at the upstream gage.

Table 10-9. Big Rock Wash – Computed 100-year Flood Event.

	Source	**Method(s)**		**100-yr Peak Discharge (cfs)**	**% Difference vs. USGS**
Upstream Gage #10263500	USGS Stream Gage	Flood-frequency Analysis, #10263500 (u/s gage)		8,680	n/a
	Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I) Mountain S-Graph	6-hr NOAA Atlas 14 Convective Storm	3,840	-56%
		Curve Number (AMC II) Mountain S-Graph	24-hr NOAA Atlas 14 General Storm	7,700	-11%
		Green and Ampt Mountain S-Graph	6-hr NOAA Atlas 14 Convective Storm	4,020	-54%
		Green and Ampt Mountain S-Graph	24-hr NOAA Atlas 14 General Storm	3,650	-58%
	Regional Regression	Equation 6.7 for Southern Desert Regions[2]		4,430	-49%
Downstream Gage #10263630	USGS Stream Gage	Flood-frequency Analysis, #10263630 (d/s gage)		n/a[1]	n/a
	Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I) Mountain S-Graph	6-hr NOAA Atlas 14 Convective Storm	5,050	n/a
		Curve Number (AMC II) Mountain S-Graph	24-hr NOAA Atlas 14 General Storm	9,810	n/a
		Green and Ampt Mountain S-Graph	6-hr NOAA Atlas 14 Convective Storm	4,090	n/a
		Green and Ampt Mountain S-Graph	24-hr NOAA Atlas 14 General Storm	3,900	n/a
	Regional Regression	Equation 6.7 for Southern Desert Regions[2]		5,770	n/a

1. The USGS gage does not have a sufficient period of record to compute the 100-year discharge (9 years of recorded peak flows).
2. The regional regression equation is based on gages with less average annual rainfall than Big Rock Wash.

10.4 West Fork Mojave River (Mojave Desert)

10.4.1 Watershed Description

The West Fork Mojave River watershed has an area of 3.2 square miles at USGS stream gage #0550. It drains adjacent to Cleghorn Road and passes under Highway 138 downstream of the gage. The gage has 9 years of overlapping data with one precipitation gage (Devore Water Company) located south of the watershed and 4 years of overlapping data with two precipitation gages (Sugar Pine and Ridge Top) located within the watershed. The largest peak occurred during the overlap with the Devore Water Company precipitation gage in 1998.

Table 10-10 provides a summary of the precipitation and peak streamflow gages for the West Fork Mojave River watershed and Figure 10-5 provides the locations of the gages.

Table 10-10. Gages for West Fork Mojave River.

Type	Station Name	Start Year of Data	End Year of Data	Elevation at Gaging Station (ft)	Source
Precipitation	Devore Water Co	1994	2007	2,698	San Bernardino County
Precipitation	Sugar Pine Ranch	2004	2007	4,360	San Bernardino County
Precipitation	Ridge Top	2004	2007	5,125	San Bernardino County
Streamflow	WF Mojave R ab Silverwood Lake nr Hesperia (10260550)	1996	2006	3,550	USGS

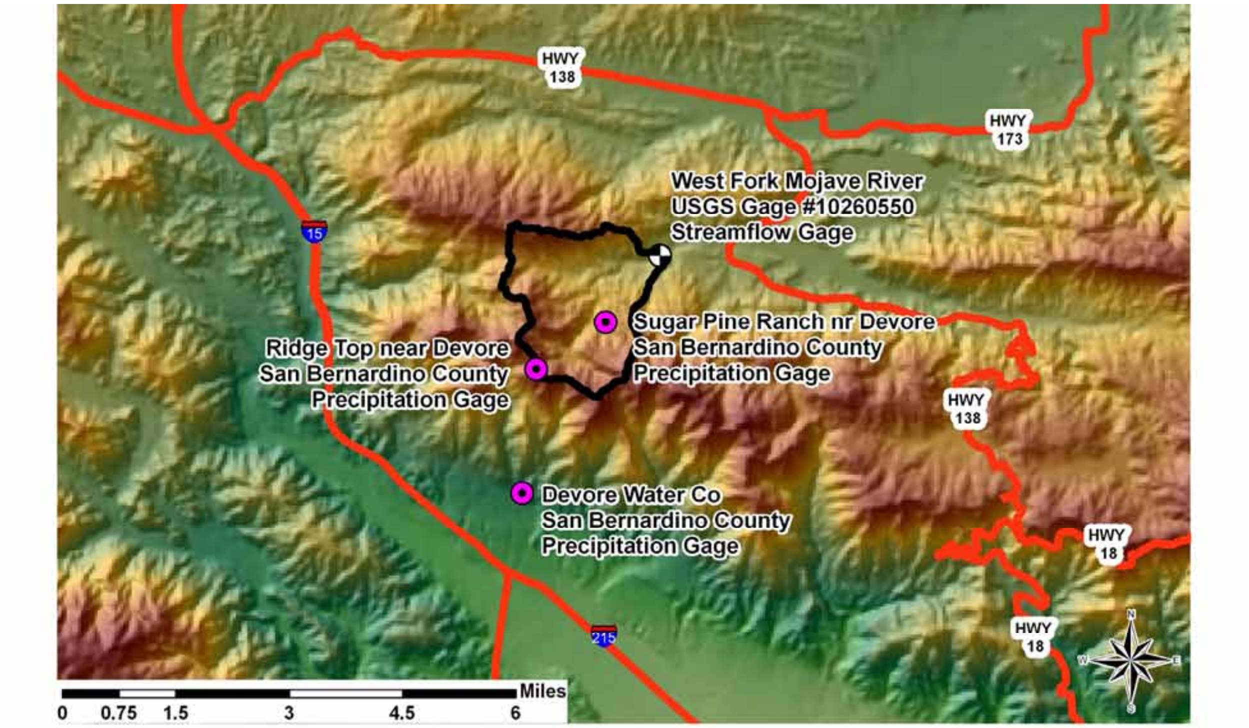


Figure 10-5. Gage Locations for West Fork Mojave River.

10.4.2 Results – Recorded Rainfall

One rainfall/flood event was modeled for the West Fork Mojave River watershed: February 23, 1998. Precipitation data from the Devore Water Company gage were used for the entire watershed because the other gages were not in operation in 1998. This is the largest peak on record (a peak occurred in 2006 when all three precipitation gages were in operation; however, the USGS recorded discharge is listed as an estimate, so the 1998 peak was modeled). Because of the high elevations and mountainous characteristics of this watershed, the San Bernardino County Mountain S-Graph was also modeled and compared with the Desert S-Graph and Maricopa County S-Graph.

Table 10-11 provides a comparison of computed peak discharges from the rainfall-runoff model and the measured peak discharge for the February 23, 1998 event. Although the San Bernardino County Mountain S-Graph provides the best results, the difference between the three modeled S-Graphs was not significant. The Green and Ampt method resulted in a zero flow value.

Table 10-11. West Fork Mojave River – February 23, 1998 Flood Event.

Source	Method(s)		Peak Discharge (cfs)	% Difference vs. USGS
USGS Stream Gage	Measured Peak		584	n/a
Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I)	San Bern. Co. Desert S-Graph	900	54%
	Curve Number (AMC I)	San Bern. Co. Mountain S-Graph	870	49%
	Curve Number (AMC I)	Maricopa County S-Graph	920	57%
	Green and Ampt	San Bern. Co. Mountain S-Graph	0	-100%

10.4.3 Results – 100-year Event

The 100-year, 6-hour Convective Storm was simulated in HEC-HMS for the West Fork Mojave River since its drainage area is less than 20 square miles. No rainfall depth-area reduction was applied because the drainage area is less than 9.6 square miles (NOAA Atlas 2 criteria).

Table 10-12 provides a summary of the computed 100-year peak discharges for West Fork Mojave River. A Flood-frequency analysis was not performed on the stream gage because it did not have a sufficient period of record. As with the recorded rainfall event, all three S-Graphs provided similar results, but in comparison to the regional regression peak discharge value, the San Bernardino County Mountain S-Graph provided the best result.

Table 10-12. West Fork Mojave River – Computed 100-year Flood Event.

Source	Method(s)		Peak Discharge (cfs)	% Difference vs. USGS
USGS Stream Gage	Flood-frequency Analysis		n/a[1]	n/a
Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I)	San Bern. Co. Desert S-Graph	2,030	n/a
	Curve Number (AMC I)	San Bern. Co. Mountain S-Graph	1,830	n/a
	Curve Number (AMC I)	Maricopa County S-Graph	2,160	n/a
	Green and Ampt	San Bern. Co. Mountain S-Graph	0	n/a
Regional Regression	Equation 6.7 for Southern Desert Regions		1,210	n/a

1. The USGS gage does not have a sufficient period of record to compute the 100-year discharge (9-years of recorded peak flows).

10.5 Fortynine Palms Creek (Mojave Desert)

10.5.1 Watershed Description

Fortynine Palms Creek watershed has an area of 8.5 square miles at USGS stream gage #3350. It flows under Highway 62 downstream of the gage and has 17 years of overlapping data with several large peaks occurring during this period. The precipitation gage is located approximately 3 miles to the northeast of the watershed. This was the only precipitation gage available for the watershed.

Table 10-13 provides a summary of the precipitation and peak streamflow gages for the Fortynine Palms Creek watershed and Figure 10-6 provides the locations of the gages.

Table 10-13. Gages for Fortynine Palms Creek.

Type	Station Name	Start Year of Data	End Year of Data	Elevation at Gaging Station (ft)	Source
Precipitation	Twentynine Palms County Yard	1961	2007	1,895	San Bern. County
Streamflow	Fortynine Palms C nr Twentynine Palms (10253350)	1961	1979	2,315	USGS

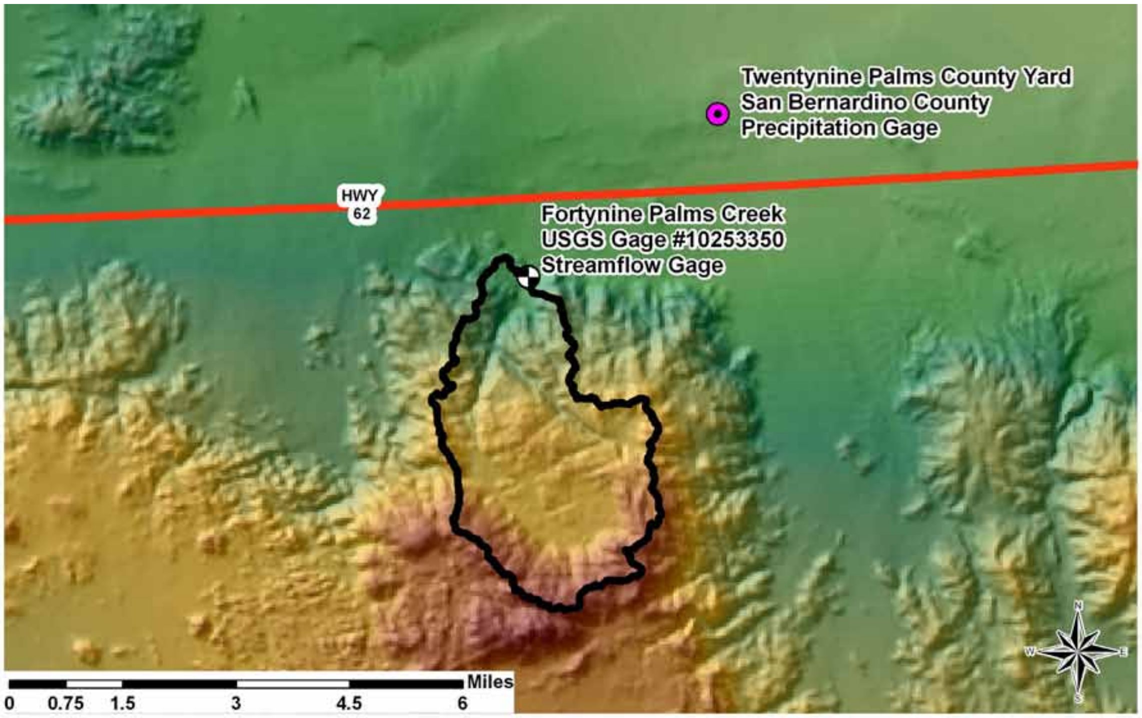


Figure 10-6. Gage Locations for Fortynine Palms Creek.

10.5.2 Results – Recorded Rainfall

One rainfall/flood event was modeled for the Fortynine Palms Creek watershed: August 7, 1963. This is the largest peak on record. Precipitation data from the Twentynine Palms County Yard gage were used for the entire watershed.

Table 10-14 provides a comparison of computed peak discharges from the rainfall-runoff model and the measured peak discharge for the August 7, 1963 event. Although the Maricopa County S-Graph provided the best result, both S-Graphs tested provided excellent results for this event.

Table 10-14. Fortynine Palms Creek – August 7, 1963 Flood Event.

Source	Method(s)		Peak Discharge (cfs)	% Difference vs. USGS
USGS Stream Gage	Measured Peak		1,240	n/a
Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I)	San Bernardino County S-Graph	1,150	7%
	Curve Number (AMC I)	Maricopa County S-Graph	1,240	0%

10.5.3 Results – 100-year Event

The 100-year, 6-hour Convective Storm was simulated in HEC-HMS for the Fortynine Palms Creek since its drainage area is less than 20 square miles. No rainfall depth-area reduction was applied because the drainage area is less than 9.6 square miles (NOAA Atlas 2 criteria).

Table 10-15 provides a summary of the computed 100-year peak discharges for Fortynine Palms Creek. A Flood-frequency analysis was not performed on the USGS gage because thirty percent of the flow values were zero values. The maximum amount of zero flow values allowed to perform a Flood-frequency analysis is twenty-five percent of the total number of flow values. As with the recorded rainfall event, both S-Graphs provided good results, but in comparison to the regional regression peak discharge value, the San Bernardino County S-Graph provided the best result.

Table 10-15. Fortynine Palms Creek – Computed 100-year Flood Event.

Source	**Method(s)**		**Peak Discharge (cfs)**	**% Difference vs. USGS**
USGS Stream Gage	Flood-frequency Analysis		n/a[1]	n/a
Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC I)	San Bernardino County S-Graph	2,840	n/a
	Curve Number (AMC I)	Maricopa County S-Graph	2,960	n/a
Regional Regression	Equation 6.7 for Southern Desert Regions		2,300	n/a

[1] The USGS gage has too many zero values (~30%) to perform a flood-frequency analysis.

10.6 Independence Creek (Owens Valley/Mono Lake)

10.6.1 Watershed Description

The Independence Creek watershed has an area of 18.1 square miles at USGS stream gage #1800. Independence Creek drains under Highway 395. It has a total of 59 years of overlapping data with several peaks occurring during this period. The Independence Onion V precipitation gage is located in the upper portion of the watershed and the Independence precipitation gage is located approximately 3 miles east of the watershed in the lower elevations.

Table 10-16 provides a summary of the precipitation and peak streamflow gages for the Independence Creek watershed and Figure 10-7 provides the locations of the gages.

Table 10-16. Gages for Independence Creek.

Type	Station Name	Start Year of Data	End Year of Data	Elevation at Gaging Station (ft)	Source
Precipitation	Independence Onion V	1948	1971	9,187	NCDC Hourly
Precipitation	Independence	1894	Present	3,950	NCDC Hourly
Streamflow	Independence Ck bl Pinyon Ck nr Indpdnce (10281800)	1923	1978	~5,300	USGS
Streamflow	Independence Ck nr Independence (10282000)	1906	1910	4,134	USGS

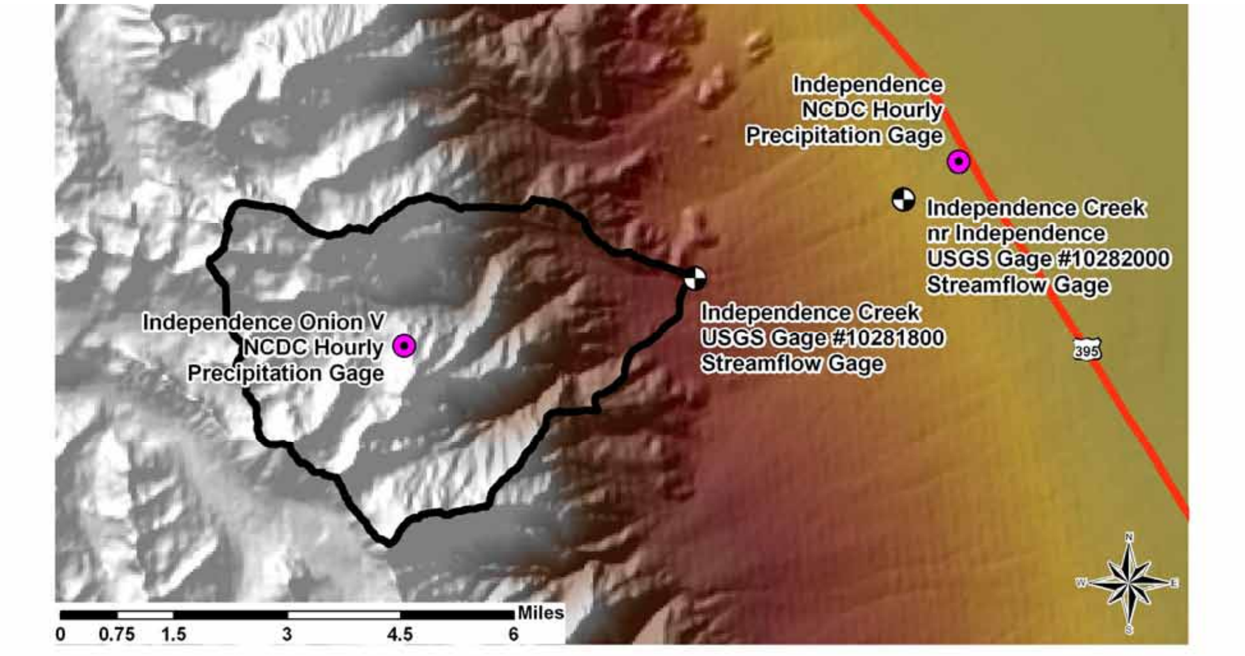


Figure 10-7. Gage Locations for Independence Creek.

10.6.2 Results – Recorded Rainfall

After a detailed review of the precipitation data for Independence Creek, no correlation was found between rainfall and peak streamflow events. Therefore this watershed's peak flows are driven by snowmelt. A much more in-depth study to model the snowmelt runoff process in HEC-HMS would be required, which was beyond the scope of this desert hydrology study. All other basins within the Owens Valley/Mono Lake Region either share this same snowmelt driven peak characteristic or do not contain overlapping gage data.

10.6.3 Results – 100-year Event

A flood-frequency analysis was performed on USGS stream gage #1800 to determine the 100-year streamflow. Regional regression equations were also applied to the watershed and the results are provided in Table 7-18. These results help to validate the use of the new regional regression equations for the Owens Valley/Mono Lake region.

Table 10-18. Independence – Computed 100-year Flood Event.

Source	Method(s)	Peak Discharge (cfs)	% Difference vs. USGS
USGS Stream Gage	Flood-frequency Analysis	260	n/a
Regional Regression	Equation 6.13 for Owens Valley/Mono Lake Region	245	-5%

10.7 Mill Creek (Northern Basin and Range)

10.7.1 Watershed Description

The Mill Creek watershed has an area of 2.1 square miles at USGS stream gage #4700. Mill Creek drains under Highway 395. It has a total of 9 years of overlapping data with two small peaks occurring during this period. The precipitation gage is located in the upper portion of an adjacent watershed.

Table 10-19 provides a summary of the precipitation and peak streamflow gages for the Mill Creek watershed and Figure 10-8 provides the locations of the gages.

Table 10-19. Gages for Mill Creek.

Type	Station Name	Start Year of Data	End Year of Data	Elevation at Gaging Station (ft)	Source
Precipitation	Milford	1948	Present	4,859	NCDC Hourly
Streamflow	Mill Ck at Milford (10354700)	1964	1973	~4,200	USGS

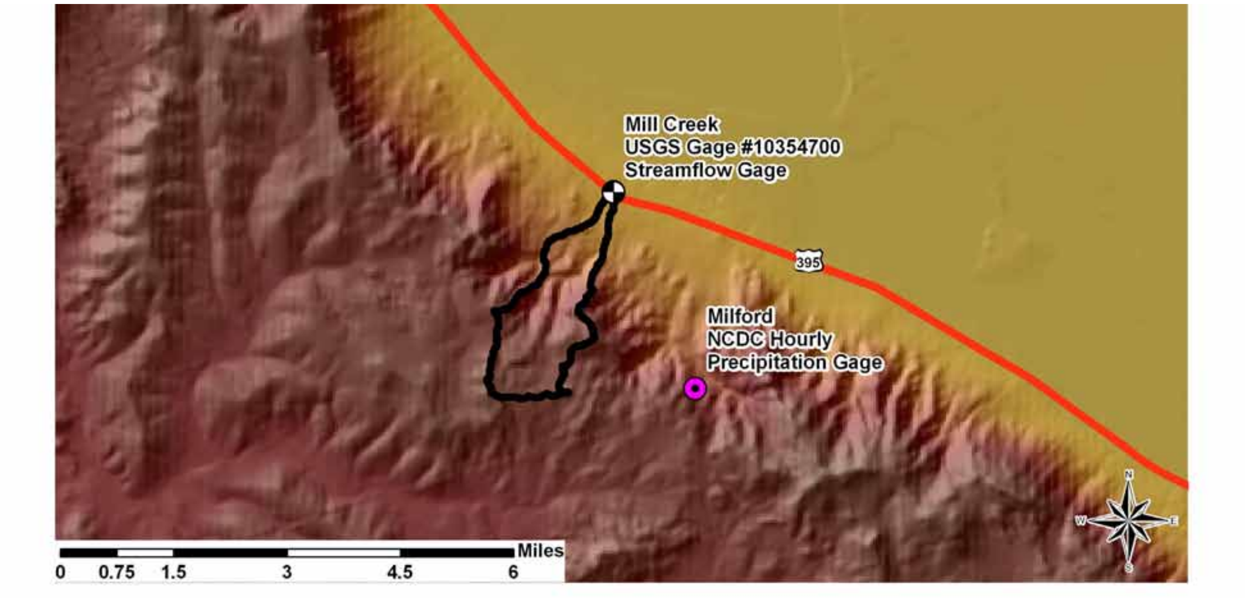


Figure 10-8. Gage Locations for Mill Creek.

10.7.2 Results – Recorded Rainfall

One rainfall/flood event was modeled for the Mill Creek watershed: January 29, 1967. This is the largest peak on record. Precipitation data from the Milford gage were used for the entire watershed.

Table 10-8 provides a comparison of computed peak discharges from the rainfall-runoff model and the measured peak discharge for the January 29, 1967 event. The rainfall-runoff model, which used the AMC II Curve Number method with the USBR (1987) S-Graph, provided good results compared to the measured peak discharge.

Table 10-20. Mill Creek – 1967 Flood Event.

Source	Method(s)		Peak Discharge (cfs)	% Difference vs. USGS
USGS Stream Gage	Measured Peak		28	n/a
Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC II)	USBR (1987) S-Graph	33	18%

10.7.3 Results – 100-year Event

The 100-year, 24-hour General Storm was simulated in HEC-HMS for Mill Creek since it is located in the Northern Basin and Range region where the general winter storm is typically dominant. No rainfall depth-area reduction was applied because the drainage area is less than 9.6 square miles (NOAA Atlas 2 criteria).

Table 10-17 provides a summary of the computed 100-year peak discharges for Mill Creek. The rainfall-runoff model results had a percent difference of 100 percent to the flood-frequency discharge. However, the flood-frequency analysis was performed on only a ten year period of recorded events, which is the minimum required to perform a Flood-frequency analysis. The HEC-HMS computed 100-year discharge compares more favorably to the regional regression equation (150 cfs vs. 220 cfs).

Table 10-17. Mill Creek – Computed 100-year Flood Event.

Source	Method(s)		Peak Discharge (cfs)	% Difference vs. USGS
USGS Stream Gage	Flood-frequency Analysis		75[1]	n/a
Rainfall-Runoff Model (HEC-HMS)	Curve Number (AMC II)	USBR (1987) S-Graph	150	100%
Regional Regression	Equation 6.19 for the Northern Basin and Range		220	193%

1. The USGS gage has the minimum period of record to perform a flood frequency analysis (10 years of recorded peak flows). Therefore, there is less confidence in the computed FFA peak discharge (5% and 95% confidence limits are 35 cfs and 327 cfs, respectively).

10.8 Discussion

The following sections discuss the methods used for calculating the flows for each basin and provide a comparison of these methods as applied to the test watersheds.

10.8.1 Rainfall Depth-Area Reduction

For all watersheds with a drainage area greater than 9.6 square miles (NOAA Atlas 2), a reduction factor was used to convert the point rainfall to an equivalent uniform depth of rainfall over the entire watershed. For the Borrego Palm Canyon and Big Rock Wash watersheds, a depth-area reduction factor was determined using the NWS HYDRO-40 method and was applied to the total storm rainfall depths for the 100-year peak events. All other watersheds modeled using HEC-HMS in this study have drainage areas less than 9.6 square miles and therefore were not adjusted by a depth-area factor.

10.8.2 Infiltration Methods

Two watershed loss methods were analyzed in this study: the SCS Curve Number Method and the Green and Ampt Infiltration Method. Appropriate Antecedent Moisture Conditions (AMC) were modeled for each basin based on the size of the watershed and the dominant storm pattern.

Flows based on the Green and Ampt Infiltration Method were computed for four of the test watersheds in the southern desert regions. These flows are compared with the flows based on SCS Curve Number Method (AMC I) and the actual recorded USGS peak discharges in Figure 10-9 for each watershed.

The Green and Ampt Method was also used to compute 100-year, 6-hour peak flows for the same four test watersheds. These flows are compared with the flows based on SCS Curve Number Method (AMC I) 100-year, 6-hour peak flows in Figure 10-10. The peak flows computed by the flood-frequency Analysis (if gage data were sufficient) and regional regression equations are also shown in Figure 7-10 for comparison.

The Green and Ampt Method did not provide reasonable results for three out of the four test watersheds. Peak discharges were computed to be zero for some basins for recorded rainfall simulations and computed 100-year events. The basis of the parameters used for the Green and Ampt Method was SSURGO soils data, or STATSGO soils data where SSURGO data were not available. The extracted hydraulic conductivity values were representative of very porous soils and therefore most, if not all, of the rainfall infiltrated resulting in no runoff. The manner in which the parameters were determined was overly complex and impractical, requiring complicated GIS data extraction and spreadsheet calculations. Based on these findings, it is recommended that the Green and Ampt Method not be used by Caltrans for desert hydrology studies and that losses should be computed based on the SCS Curve Number Method.

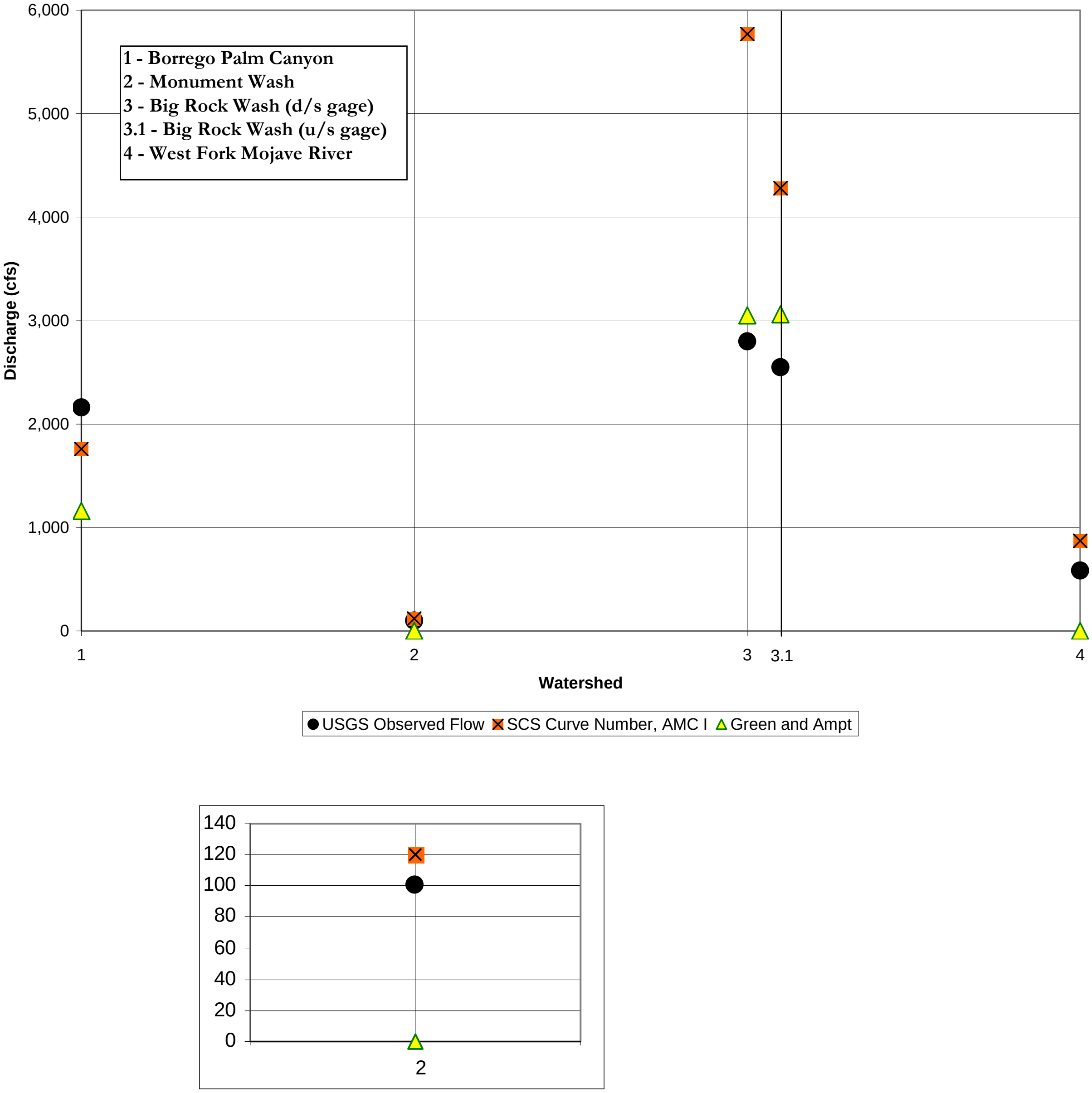


Figure 10-9. Loss Method Comparison – Recorded Rainfall Events.

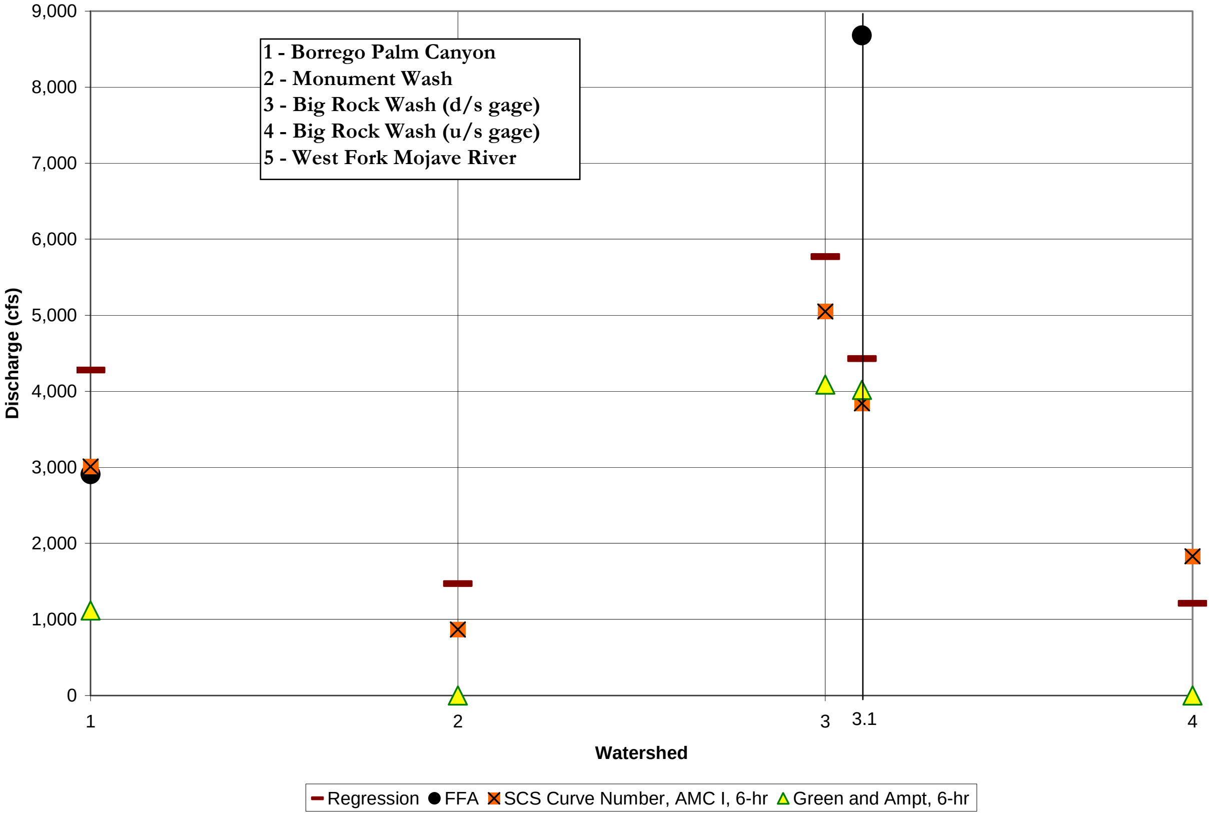


Figure 10-10. Loss Method Comparison – 100-Year Event.

10.8.3 Transformation Methods

Four S-Graphs were analyzed in this study to calculate the transformation of precipitation to excess runoff: San Bernardino County Desert S-Graph, San Bernardino County Mountain S-Graph, Maricopa County Desert/Rangeland S-Graph, and USBR S-graph. S-Graphs for each test watershed were selected based on the desert region and the watershed characteristics. Figure 10-11 provides a comparison of the transformation methods for the recorded rainfall event. Figure 10-12 provides a comparison of the transformation methods for the 100-year event.

The San Bernardino County Mountain S-Graph was used in the Big Rock Wash and West Fork Mojave River watersheds due to the high elevations of these watersheds and the mountainous terrain in the upper portions. The San Bernardino County Desert S-Graph was applicable to all of the other basins in the southern desert regions. When compared in the rainfall-runoff model, the Maricopa County S-Graph and San Bernardino County Desert S-Graph provided similar results, although the San Bernardino County Desert S-Graph provided slightly better results on average. Therefore, it is recommended that transformation be computed based on the San Bernardino County Desert S-Graph for the sake of consistency when both S-Graphs are applicable. The USBR S-Graph is applicable to the Northern Basin and Range Region.

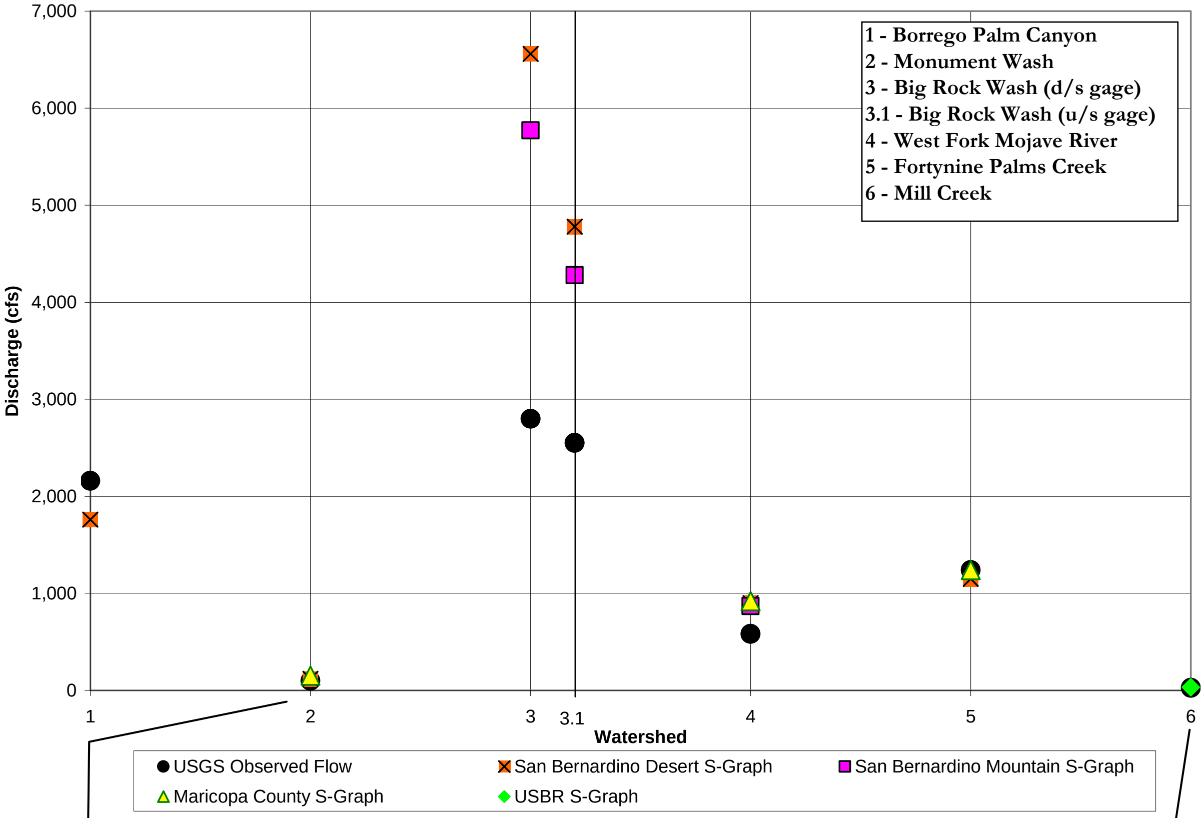
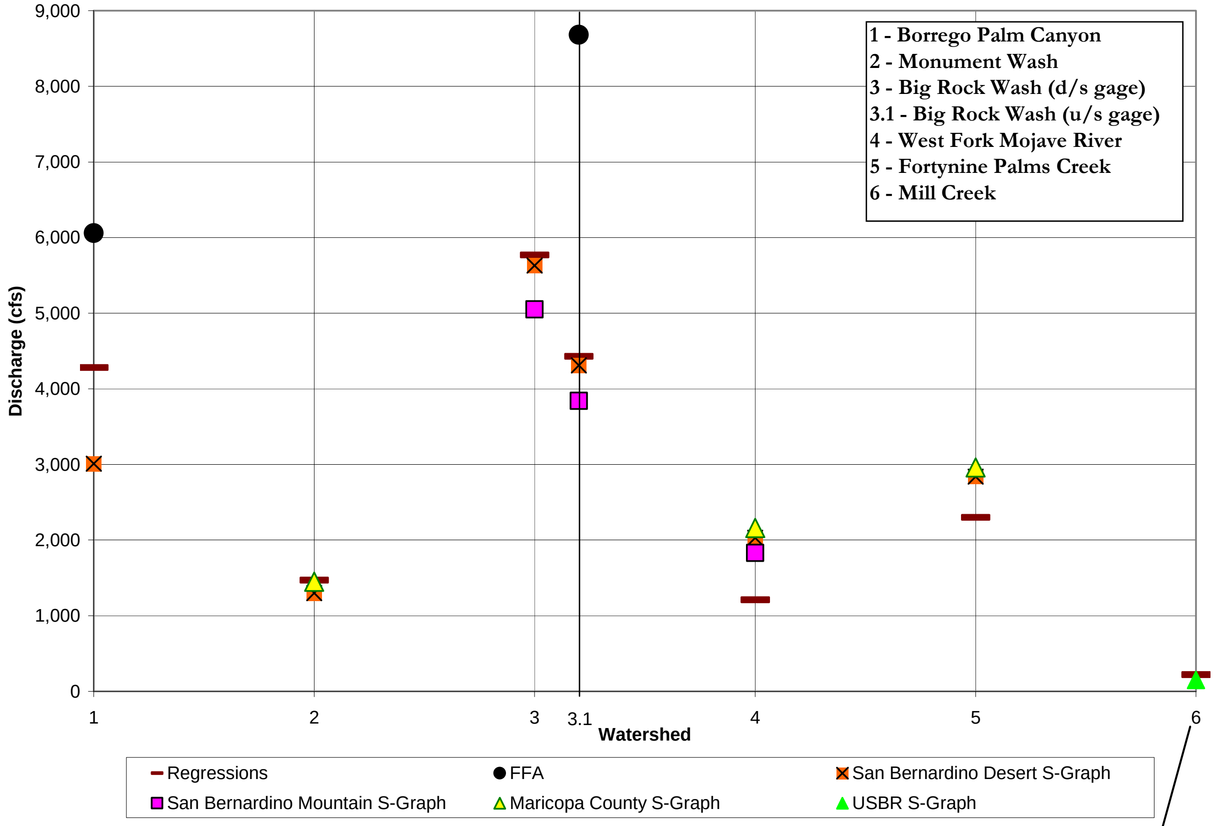


Figure 10-11. Transformation Method Comparison – Recorded Rainfall Event.



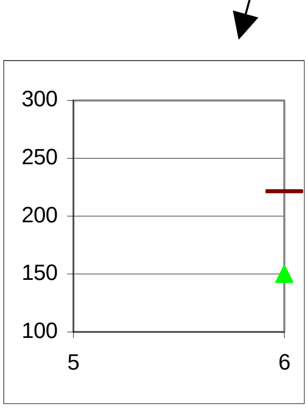


Figure 10-12. Transformation Method Comparison – 100-year Event.

10.8.4 Antecedent Moisture Condition

The Antecedent Moisture Condition (AMC) generally represents the condition of the watershed surface cover and soils preceding a particular storm and corresponds to its runoff potential. AMC I represents dry soils that will have the lowest runoff potential, AMC II represents an average runoff potential, and AMC III has a high runoff potential and is often used to represent saturated soils. Because all the watersheds in this study are located in the desert regions, only AMC I and AMC II were studied as saturated conditions rarely exist in the desert.

Flows based on AMC I were computed for the first six basins for the recorded-rainfall events. Independence Creek and Mill Creek are located in an area that is dominated by general winter storms and they are best represented with AMC II. Borrego Palm Canyon and Big Rock Wash flows were computed with AMC II as well as AMC I since their drainage areas exceed 20 square miles. Figure 10-13 provides a comparison of the computed flows based on the recorded-rainfall events and the actual recorded USGS flow for each watershed. For the watersheds calculated with only AMC I (Monument Wash, West Fork Mojave, and Fortynine Palms), the results were very favorable in comparison to the USGS observed flows. For Mill Creek (AMC II only), the computed peak discharge was also very favorable to the observed flow. Therefore, the use of AMC II in the Northern Basin and Range and AMC I in the southern desert regions appears to be valid.

For Borrego Palm Canyon and Big Rock Wash, AMC I provided the best result when compared to the observed event. AMC II overestimated the peak discharge.

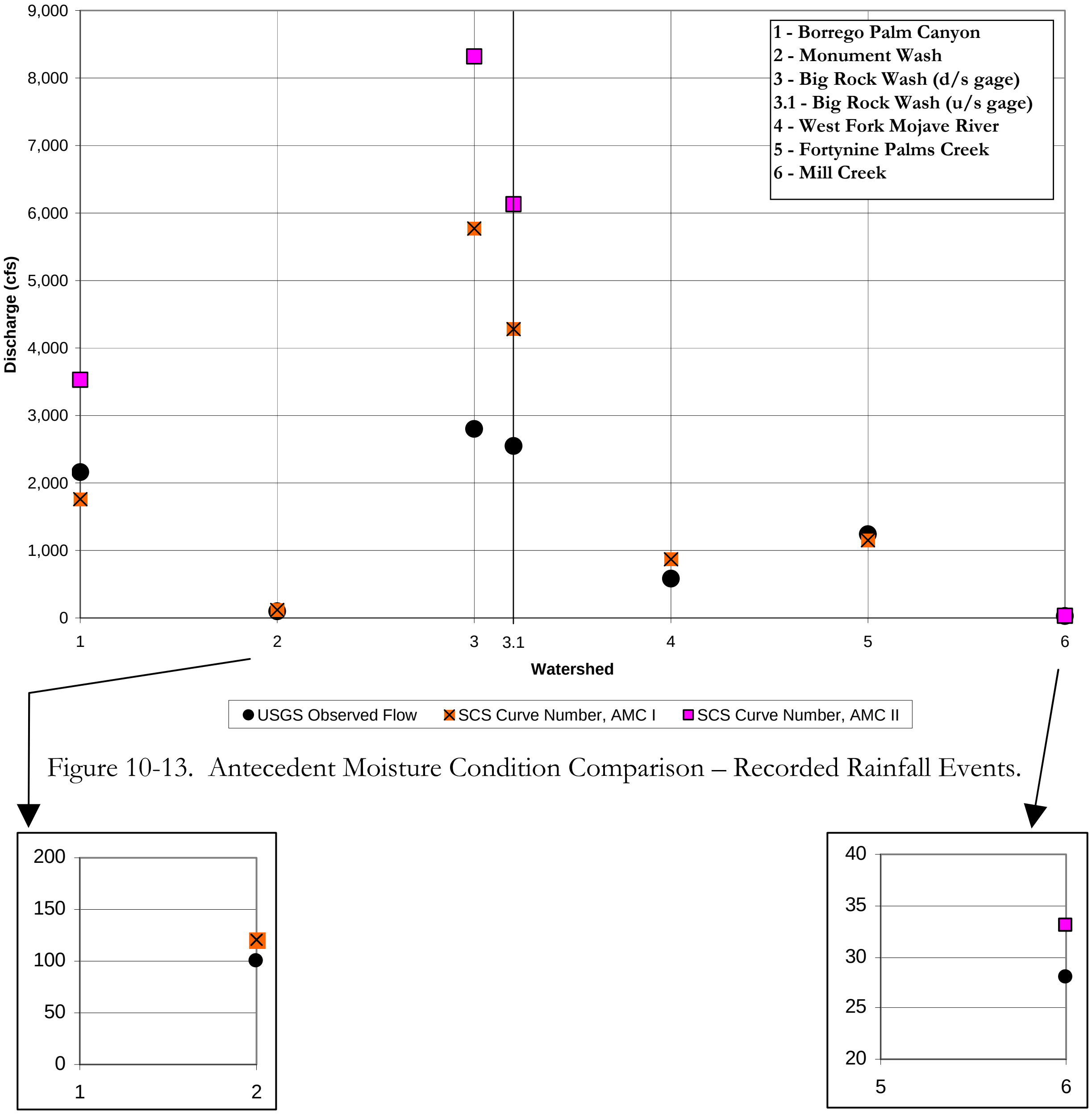


Figure 10-13. Antecedent Moisture Condition Comparison – Recorded Rainfall Events.

10.8.5 Storm Duration and Temporal Distribution

The 100-year, 6-hour storm was computed with AMC I for all the southern desert region watersheds to reflect a convective storm. The 100-year, 24-hour storm was computed with AMC II to simulate a general storm for Borrego Palm Canyon and Big Rock Wash because their drainage areas are great than 20 square miles and therefore they could be subject to convective storms or general storms. Independence Creek and Mill Creek reside in the Northern Basin and Range and Owens Valley/Mono Lake Region, respectively, where general storms are prevalent. Therefore, the 100-year, 24-hour storm was computed with AMC II for these two watersheds.

Figure 10-14 provides a comparison of the computed 100-year flows from HEC-HMS, flood-frequency analysis (if gage data were sufficient), and regional regression equations. Gage data are considered sufficient if the period of record is greater than or equal to 10 years and if less than 25% of the peak flow values have a zero value. For the watersheds calculated with the 100-year, 6-hour Convective Storm and AMC I curve numbers (Monument Wash, West Fork Mojave, and Fortynine Palms), the results were favorable in comparison to the results from the regional regression equation (flood-frequency analyses were not completed on these watersheds due to insufficient data). For Mill Creek where only the 100-year, 24-hour General Storm (AMC II) was computed, the result was also very favorable to the regional regression discharge. Therefore, the assumption of using the 100-year, 24-hour General Storm (AMC II) in the Northern Basin and Range and the 100-year, 6-hour Convective Storm (AMC I) in the small southern desert regions appears to be valid.

Borrego Palm Canyon and Big Rock Wash were calculated using both the 100-year, 6-hour Convective Storm (AMC I) and the 100-year, 24-hour General Storm (AMC II) because they are located in the southern desert regions and the basins are greater than 20 square miles and therefore could be subject to either type of storm.

For Borrego Palm Canyon, the 100-year, 6-hour Convective Storm (AMC I) provided the best result when compared to both the flood-frequency analysis flow and the regional regression discharge.

For Big Rock Wash, the 100-year, 6-hour Convective Storm (AMC I) provided the best result when compared to the regional regression equation flow for both the upstream and downstream gage. The regional regression equation was based on watersheds that receive less average annual rainfall than the Big Rock Wash watershed. Therefore, the regional regression equation could underpredict the peak discharge for this watershed. For the upstream gage where a flood-frequency analysis was performed, the 100-year, 24-hour General Storm (AMC II) provided the best result. Since this gage has a long period of record (83 years) and the regional regression equation may underpredict, the 100-year, 24-hour General Storm (AMC II) is considered the most suitable for the Big Rock Wash watershed.

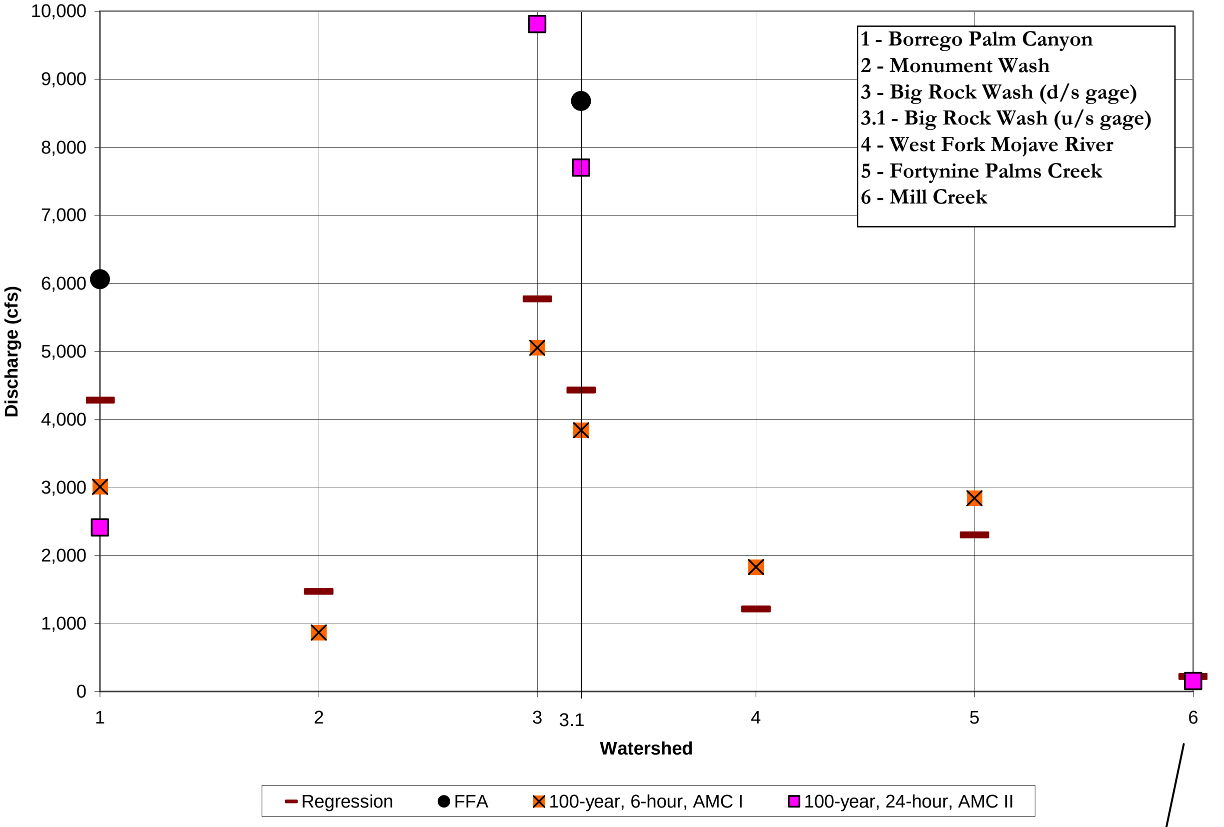
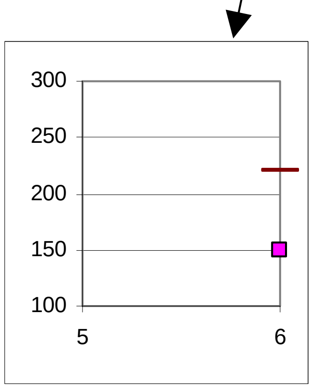


Figure 10-14. Storm Duration and Temporal Distribution – 100-year Event.



10.9 Recommended Approach

A summary of the major findings from the rainfall-runoff simulation are provided below.

Infiltration Methods

- The SCS Curve Number and Green and Ampt infiltration methods were analyzed.
- The Green and Ampt method greatly overestimated infiltration losses for the majority of test watersheds where it was applied, resulting in zero flow values in some cases.
- The SCS Curve Number method provided favorable results for the majority of watersheds and is recommended for use by Caltrans for desert hydrology studies.

Transformation Methods

- Four S-Graphs were analyzed: San Bernardino County Desert S-Graph, San Bernardino County Mountain S-Graph, Maricopa County Desert/Rangeland S-Graph, and USBR S-Graph.
- The San Bernardino County Mountain S-Graph is recommended for watersheds with mountainous terrain/high elevations in the upper portions.
- Simulation results using the San Bernardino County Desert S-Graph and Maricopa County Desert/Rangeland S-Graph were comparable.
- For the sake of consistency, the San Bernardino County Desert S-Graph is recommended for use in watersheds in the southern desert regions with limited or no mountainous terrain/high elevations.
- The USBR (1987) S-Graph is recommended for watersheds in the Northern Basin and Range.

Antecedent Moisture Condition

- Two Antecedent Moisture Conditions were analyzed for the recorded rainfall events: AMC I and AMC II. The differences in AMC I vs. AMC II are reflected in the SCS curve numbers.
- AMC I was analyzed for test watersheds in the southern desert regions. AMC II was analyzed for test watershed southern desert regions greater than 20 square miles and the Northern Basin and Range.
- AMC I provided the best results for watersheds in the southern desert region, including those over 20 square miles.
- AMC II provided favorable results for the test watershed in the Northern Basin and Range region.

Storm Duration and Temporal Distribution

- Two storm duration/temporal distributions were analyzed: 100-year, 6-hour Convective Storm (AMC I) and 100-year, 24-hour General Storm (AMC II).
  - The 100-year, 6-hour Convective Storm with AMC I was analyzed for test watersheds in the southern desert regions.
  - The 100-year, 24-hour General Storm with AMC II was analyzed for test watersheds exceeding 20 square miles in the southern desert regions and the test watershed in the Northern Basin and Range region.
- For watersheds in the southern desert regions with a drainage area *less than* 20 square miles, the 100-year, 6-hour Convective Storm (AMC I) provided favorable results and is recommended for use by Caltrans in estimating the 100-year peak discharge or other large flows.
- For the two watersheds in the southern desert regions with a drainage area *greater than* 20 square miles (Borrego Palm Canyon and Big Rock Wash), the results were mixed.
  - The 100-year, 6-hour Convective Storm (AMC I) provided the best results for Borrego Palm Canyon in the Colorado Desert region.
  - The 100-year, 24-hour General Storm (AMC II) provided the best results for the more mountainous Big Rock Wash watershed in the Antelope Valley region.
  - In each case, the storm that produced the largest peak discharge was also the one that provided the best results.
- For watersheds greater than 20 square miles in the southern desert regions, both the 6-hour Convective Storm (AMC I) and the 24-hour General Storm (AMC II) should be analyzed and the larger of the two peak discharges selected.
- Watersheds along the Eastern Sierra in the Owens Valley/Mono Lake region are dominated by snowmelt-driven peaks. The use of regional regression equations is recommended where streamgage data are not available; otherwise, hydrologic modeling could be performed with snowmelt simulation, which is beyond the scope of this study.
- For the Northern Basin and Range region, the 100-year, 24-hour General Storm (AMC II) provided favorable results and is recommended for use by Caltrans in estimating the 100-year peak discharge or other large flows.

Recommendations for desert hydrology, including those for flood-frequency analysis, regional regression, and rainfall-runoff simulation, are summarized in the hydrology flowchart (Figure 10-15).

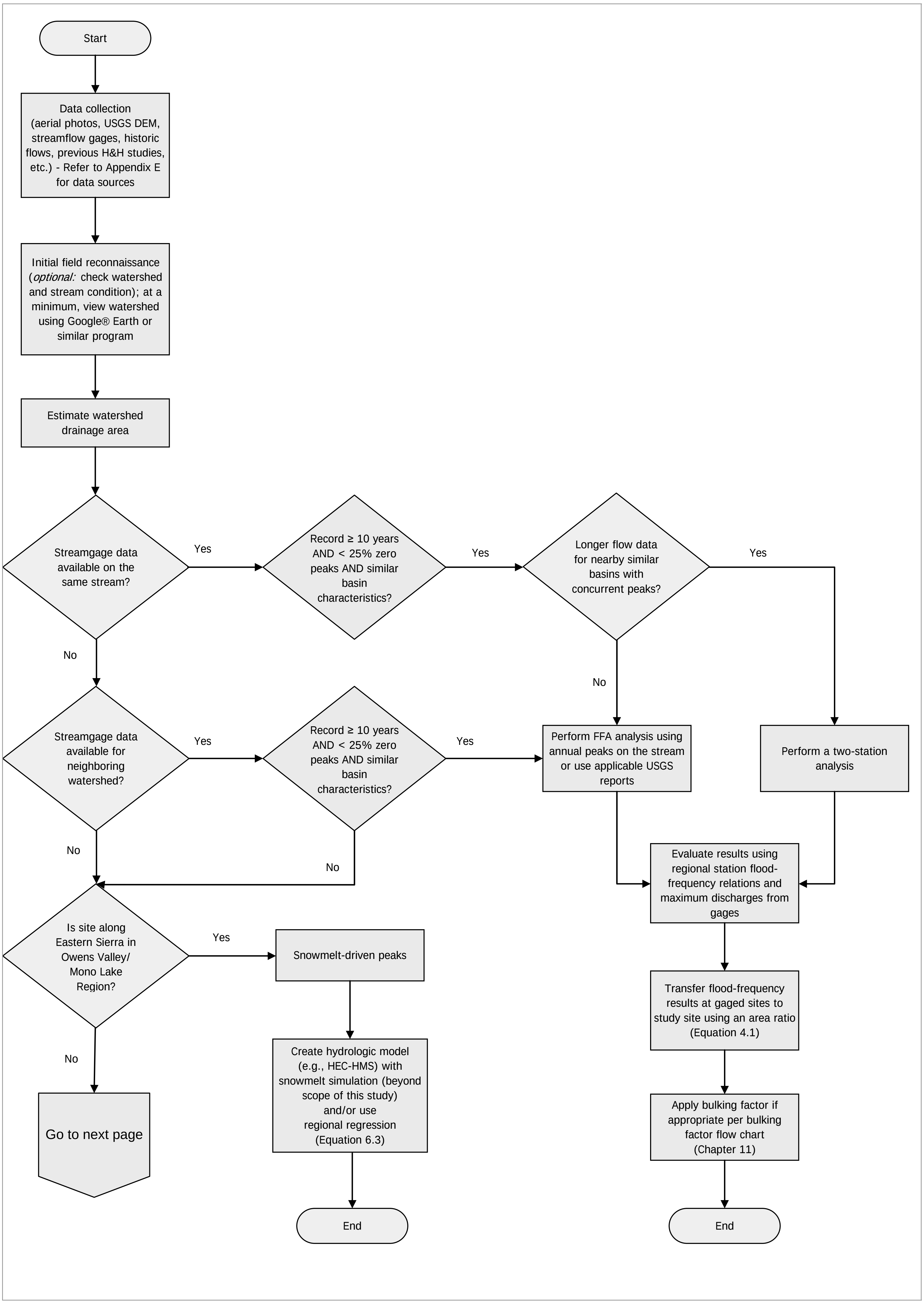


Figure 10-15. Hydrology Flowchart, Part 1 of 3.

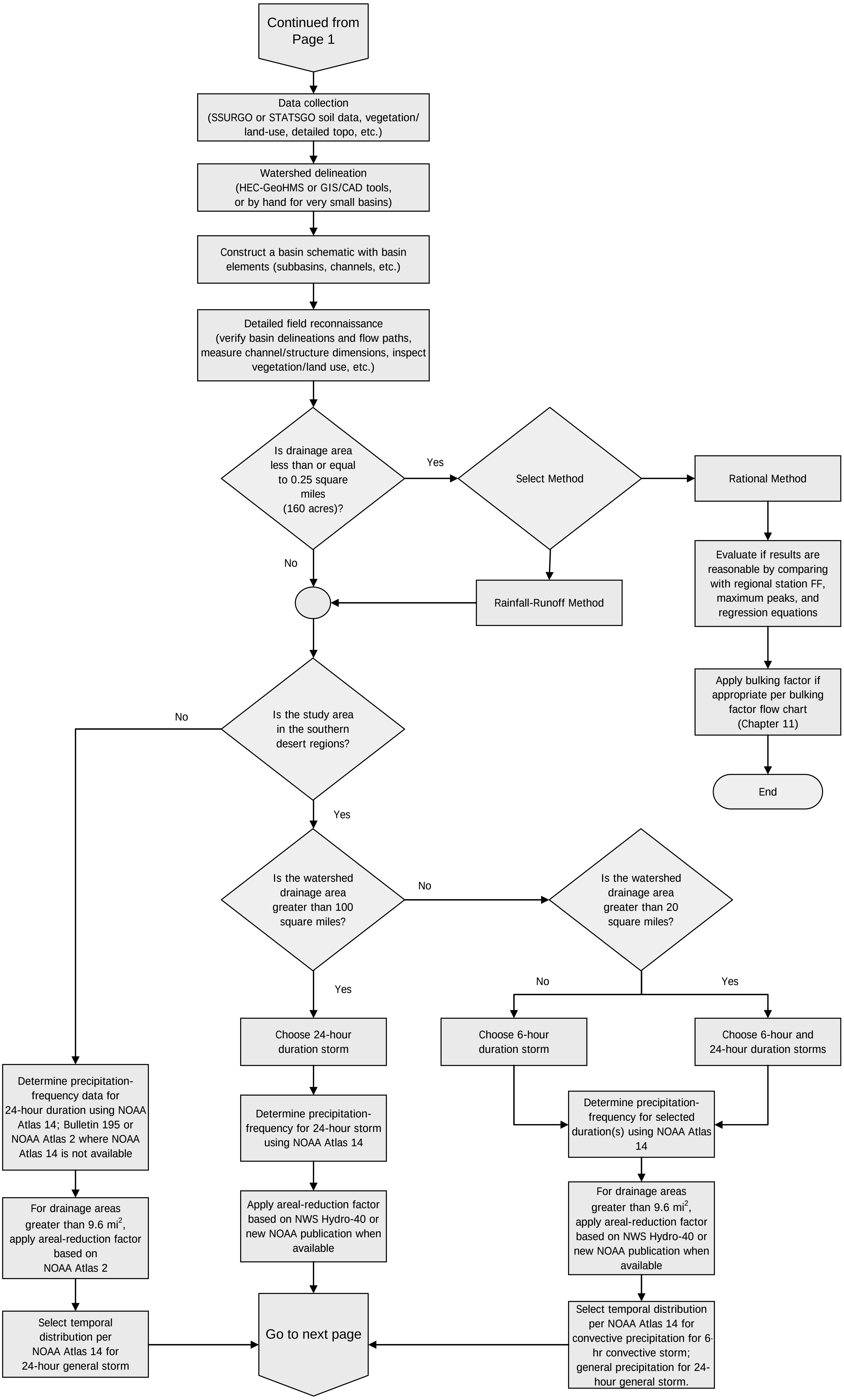


Figure 10-16. Hydrology Flowchart, Part 2 of 3.

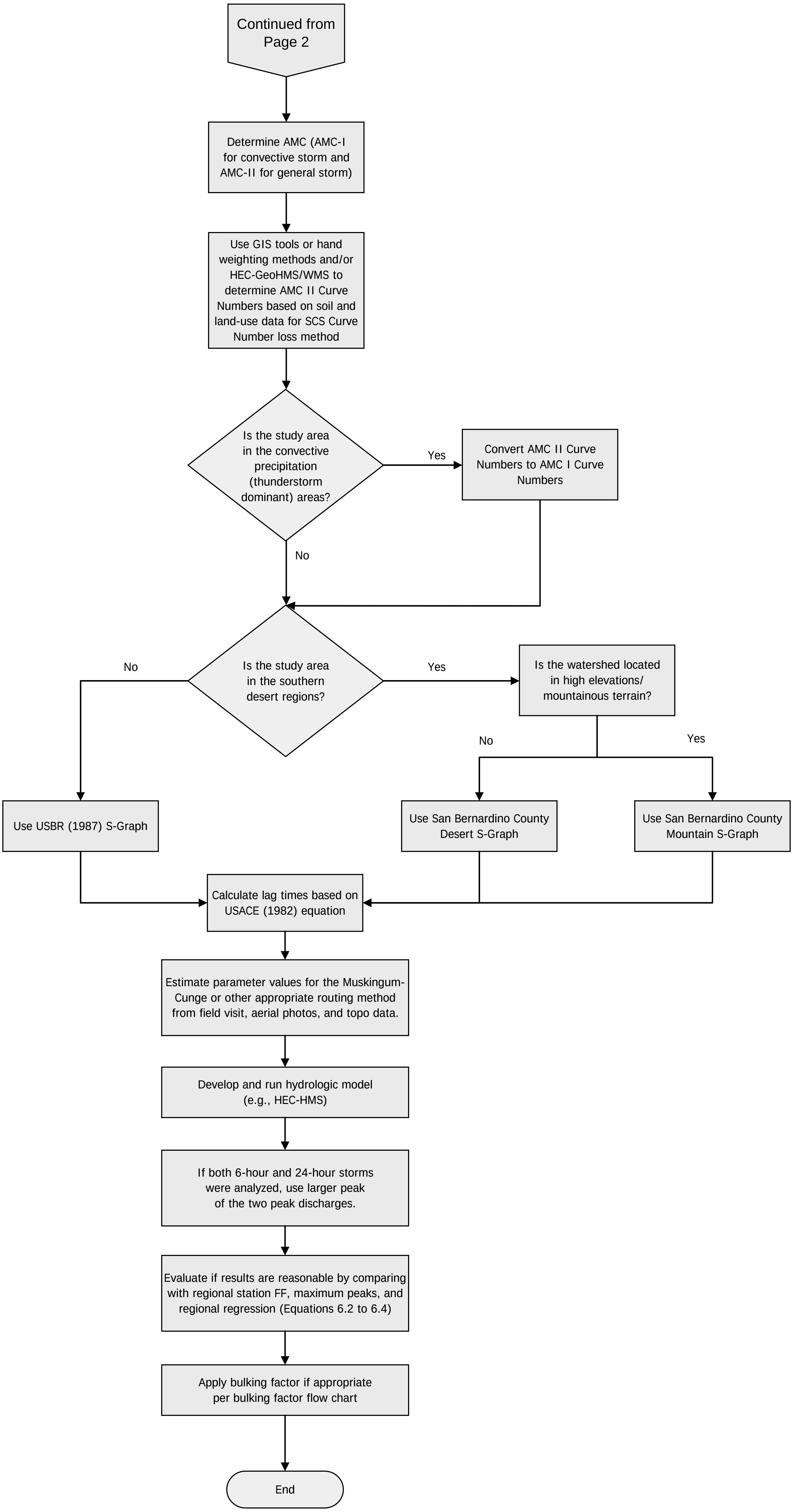


Figure 10-17. Hydrology Flowchart, Part 3 of 3.

11 SEDIMENT/DEBRIS BULKING

Bulking has been defined as increasing the water discharge to account for high concentrations of sediment in the flow (Richardson et al., 2001). Mud and debris flows, which can significantly increase the volume of flow transported from a watershed, most often occur in mountainous areas subject to wildfires with subsequent soil erosion, and in arid regions near alluvial fans and other zones of geomorphic and geologic activity.

For the design of facilities in areas prone to high sediment and debris concentrations, the use of a bulking factor can provide for an adequately-sized bridge opening. Described in the first part of this chapter are bulking factor equations, types of sediment/water flow, debris flow potential, alluvial fans, and wildfire impacts. The second part of the chapter includes agency bulking methods, the recommended approach for California's desert regions, and an example application.

11.1 Bulking Factor Equations

Bulking is the increase in flow rate due to the inclusion of sediment/debris in the flow. A bulking factor (BF) is generally applied to the peak flow to obtain the total (bulked) peak flow, and serves to introduce a safety factor into the hydraulic design (Hamilton and Fan, 1996).

For an undeveloped watershed where the entire area contributes debris, the bulked peak flow is expressed by:

$$Q_B = Q_w + Q_s \tag{11.1}$$

where Q_B is the bulked peak discharge, Q_w is the peak clear water discharge, Q_s is the volumetric sediment discharge.

The bulking factor (BF) is the ratio of the bulked discharge to the clear water discharge:

$$BF = (Q_w + Q_s)/Q_w \tag{11.2}$$

Using this bulking factor, the bulked peak discharge may be defined as:

$$Q_B = BF * Q_w \tag{11.3}$$

The bulking factor may be computed based on the concentration of sediment in the flow:

$$BF = \frac{1}{1-\frac{C_v}{100}} \tag{11.4}$$

where C_v is the sediment concentration in percent volume.

In the case of a partially-developed watershed or if a debris-control structure reduces the amount of sediment available for transport, the bulking factor can be applied on a proportional basis.

11.2 Types of Sediment/Water Flow

The behavior of flood flows can vary significantly, depending on the concentration of sediment/debris in the mixture. Three types of sediment/water flow are typically defined – normal streamflow (or water flood), hyperconcentrated flow (or mud flood), and debris flow (or mud flow). It should be noted that the divisions between these flow types have been defined in a number of ways by different researchers (Bradley, 1986). This study generally follows the classification developed by O'Brien (1986), as outlined in the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) Sediment and Erosion Design Guide (Resource Consultants & Engineers, 1994), and shown in Table 11-1.

11.2.1 Normal Streamflow (Water Flood)

For normal streamflow conditions, the sediment load has a minimal impact on the behavior of the flow. This condition can be modeled using standard hydraulic methods for a Newtonian fluid. A 20-percent sediment concentration by volume is considered by most researchers as the upper limit for normal streamflow. This sediment concentration corresponds to a bulking factor of 1.25; however, a bulking factor is not typically used for streams or washes experiencing normal streamflow. Although sediment concentrations up to 20 percent are possible for normal streamflow, it typically has less than 5- to 10-percent sediment concentration by volume (USGS, 2005a). Sediment is transported by normal streamflow as conventional suspended load and bedload.

11.2.2 Hyperconcentrated Flow (Mud Flood)

Fluid properties and sediment-transport characteristics change under hyperconcentrated flow, as large volumes of sand can be transported throughout the water column, and mixture no longer behaves strictly as a Newtonian fluid. Nevertheless, basic hydraulic and sediment transport equations and models are generally accepted in the range of hyperconcentrated flow. A 40-percent sediment concentration by volume is the approximate upper limit of hyperconcentrated flow, which corresponds to a bulking factor of 1.67 (see Table 11-1).

11.2.3 Debris Flow (Mud Flow)

The properties and behavior of debris and mud flows are very different from normal streamflow, or even hyperconcentrated flow. A key distinction is that the flow behavior of a debris flow is primarily controlled by the sediment and the composition of the sediment/debris mixture (Krone and Bradley, 1990). The amount of clay, in particular, has a major impact on the yield strength of the mixture. A 50-percent sediment concentration by volume is the approximate upper limit for debris flows, which corresponds to a bulking factor of 2.0.

For a debris flow, the sediment/water mixture is no longer a Newtonian fluid, and basic hydraulic and sediment transport equations do not apply. If detailed modeling of debris/mud flows is required, a model with specific debris flow capabilities (e.g., FLO-2D) should be used rather than standard hydraulic models such as HEC-RAS (River Analysis System). In general practice, however, bulked flows based on bulking factors of up to 2.0 are often used in conjunction with standard hydraulic models.

As described by O'Brien (2006), during typical debris flow events, clear-water flows arrive first from basin rainfall-runoff. These flows are followed by a surge or "frontal wave" of mud and debris (40-

to 50-percent concentration by volume). When the peak water discharge arrives, the average sediment concentration typically drops to the range of 30- to 40-percent by volume. On the falling limb of the hydrograph, surges of higher sediment concentration may occur.

Large flood discharges, such as the 100-year flood, may contain too much water to produce a debris/mud flow event. Therefore, smaller events (e.g., 10-year or 25-year) may actually have a higher likelihood of producing a debris event and would have a higher bulking factor.

Table 11-1. Classifications of Flows by Sediment Concentration (adapted from Bradley, 1986).

Bulking Factor							
0	1.11	1.25	1.43	1.67	2.00	2.50	3.33
Sediment Concentration by Weight (100% by WT = 1 x 10^6 ppm)							
0	23	40	52	63	72	80	87
Sediment Concentration by Volume (specific gravity = 2.65)							
0	10	20	30	40	50	60	70
	Normal Streamflow		Hyperconcentrated Flow	Debris Flow		Landslide	

As noted in Table 11-1, sediment “flows” with more than 50-percent sediment concentration by volume are generally considered landslides rather than debris flows.

11.3 Debris Flow Potential

11.3.1 Debris Hazard Areas

Locations that have a greater potential for debris-flow hazards include (USGS, 1997b):

- At or near the foot of a steep slope, especially slopes of 26 degrees (1V:2H) or steeper.
- At or near the junctions of ravines with canyons.
- Near the upper points of alluvial fans.
- Within alluvial fans.

Mass movement (wasting) of rock, debris, or earth can take the form of falls, slides, or flows. The impact of mass wasting on sediment production from the watershed can be very significant. The amount of sediment that can enter the stream channels will depend on the hydrologic and geologic conditions, as well as the location of mass wasting relative to the drainage system. Mass wasting events are the primary source of bulked flows.

11.3.2 Soil Slips

Debris flows often begin with soil slips, which tend to form on steep slopes. Flowing mud and rocks will accelerate downslope until the slope is gentler, where the flow slows and stops, depositing mud, rock, and vegetation (USGS, 1997b). Figure 11-1 shows the likelihood of soil slips versus slope angle. Soil slips are the most common, and are most likely to accelerate, at slopes of 26 degrees (1V:2H) or steeper. Soil slips are also common on slopes between 18 degrees (1V:3H) and 26 degrees; however, the potential for acceleration down the slope is much less than for the steeper slopes.

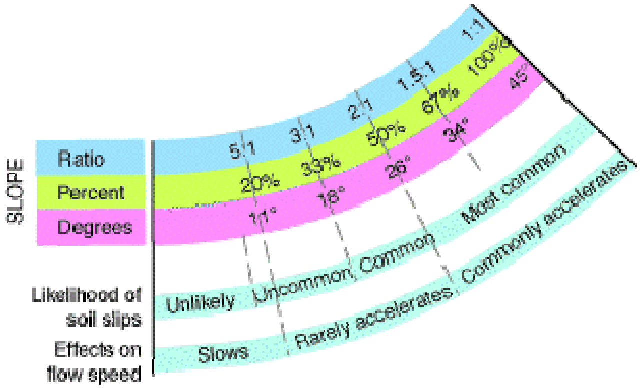


Figure 11-1. Likelihood of Soil Slips vs. Slope Angle (USGS, 1997b).

Locations where relatively flat terrain, such as an alluvial fan or the floodplain of a narrow canyon, adjoins a steep slope, such as a canyon wall or a steep mountain front, are most likely to be exposed to debris flows from small, steep drainage channels. The size of the debris flow increases with a longer slope, and the speed of a debris flow increases with steeper slopes. If channelized, large debris flows can travel distances of a mile or more (USGS, 1997b).

11.3.3 Geologic Conditions

The USGS found that for areas underlain by sedimentary rocks and fractured basement rocks, essentially all of the debris flows were generated on hillsides with slopes of 26 degrees (1V:2H) or steeper (USGS, 1997b). Such conditions are found in the Transverse Ranges, which include the San Gabriel and San Bernardino Mountains along the southern and southwestern borders of the Antelope Valley (Region 3) and Mojave Desert (Region 4), respectively.

Not included as high potential for generation of debris flows, even with slopes of 26 degrees (1V:2H) or steeper, are upland areas underlain by relatively unfractured basement rocks – primarily granitic rocks, including those found in much of the Peninsular Ranges. This is based on past observations that slopes underlain by such rocks rarely generate debris flows (USGS, 1997b). The Peninsular Ranges include the San Jacinto, Santa Rosa, and Laguna Mountains, which are located along the western border of the Colorado Desert (Region 1). It should be note that while debris flows are less prevalent in the Peninsular Ranges, they can and do still occur under the right geologic conditions.

11.3.4 Antecedent Rainfall

The USGS (1997b) compared historic rainfall records and times of debris flows for southern California to determine how much rainfall is needed to trigger debris flows and what kinds of storms most often trigger them. For unburned areas of chaparral, sage, or annual vegetation cover, the slope typically had received at least 10 inches of total seasonal rainfall prior to a significant storm event. For recently burned areas, which have many more debris flows than unburned areas, no prior rainfall was required for debris flows to occur. This is because a hydrophobic layer in the soil can be created by intense fires. This is a layer that repels water and increases runoff from later storms, increasing the likelihood of debris flows.

11.4 Alluvial Fans

An alluvial fan has been defined as a "sedimentary deposit located at a topographic break, such as the base of a mountain front, escarpment, or valley side, that is composed of fluvial and/or debris flow sediments and which has the shape of a fan either fully or partially extended" (National Research Council, 1997). An alluvial fan is essentially a depositional area, where the sediment-carrying capacity of the stream or wash is reduced by a greatly increased flow area. On an alluvial fan, flow paths are uncertain and ever changing – they may diverge and then rejoin downstream due to debris flows, water flows, or a mixture of the two. The sediment content of a flow through an alluvial fan may vary from negligible to more than 50 percent sediment and debris (Federal Highway Administration, 2002).

Much research has been devoted to analyzing alluvial fans, and detailed discussion of this topic is beyond the scope of the current study. Instead, the purpose of this section is to provide a brief introduction to alluvial fans in the context of selecting an appropriate sediment/debris bulking factor. More comprehensive references should be consulted for a detailed treatment of alluvial fans, including those from FEMA and the U.S. Army Corps of Engineers:

- *Guidelines and Specifications for Flood Hazard Mapping Partners*, Appendix G: Guidance for Alluvial Fan Flooding Analyses and Mapping (FEMA, 2003b)
- *Guidelines of Risk and Uncertainty Analysis in Water Resources Planning* (U.S. Army Corps of Engineers, 1992)
- *Alluvial Fans in California – Identification, Evaluation, and Classification* (U.S. Army Corps of Engineers, 2000b)

11.4.1 Identifying Alluvial Fans

Alluvial fans can be identified from soils maps, geologic maps, topographic maps, and aerial photographs. In addition to these sources, a site visit is invaluable in defining alluvial fans and their characteristics. Appendix F provides an excerpt from *Alluvial Fans in California* entitled "Steps for Identifying, Evaluating, and Classifying Alluvial Fans."

Active and inactive alluvial fans are described as follows on FEMA's Flood Hazard Mapping website (www.fema.gov/plan/prevent/fhm/fq_afdef.shtm):

> Active alluvial fan flooding is indicated by three related criteria: (a) flow path uncertainty below the hydrographic apex, (b) abrupt deposition and ensuing erosion of sediment as a stream or debris flow loses its competence to carry material eroded from a steeper, upstream source area, and (c) an environment where the combination of sediment availability, slope,

and topography creates an ultrahazardous condition for which elevation on fill will not reliably mitigate the risk.

Inactive alluvial fan flooding is similar to traditional riverine flood-hazards, but occurs only on alluvial fans. It is characterized by flow paths with a higher degree of certainty in realistic assessments of flood risk or in the reliable mitigation of the hazard.

For active alluvial fans, the use of a two-dimensional hydrodynamic model such as FLO-2D (O'Brien, 2006) should be considered. FLO-2D can simulate clear water, mud, and debris flooding on alluvial fans, and the Corps of Engineers considers the model to be "reliable for most alluvial fan problems" (U.S. Army Corps of Engineers, 2000b).

11.4.2 Highway Alignment and Bulking Factors

The Highway Design Manual (Caltrans, 2006) illustrates three alternative highway alignments across an alluvial fan (see Figure 11-2):

(A) Crosses at a single definite channel

(B) Crosses a series of unstable indefinite channels

(C) Crosses a widely dispersed and diminished flow

At location (A) where the flow is confined to a single, well-defined channel, a larger bulking factor would typically be selected. At location (C) where the flow is more widely dispersed and much of the sediment and debris has already been deposited outside of the multiple channels, a lower bulking factor may be reasonable (depending on specific site conditions and engineering judgment). For middle location (B), which is the least desirable alignment, the selection of an appropriate bulking factor is less clear; however, the distance from the apex to the site would factor into the decision.

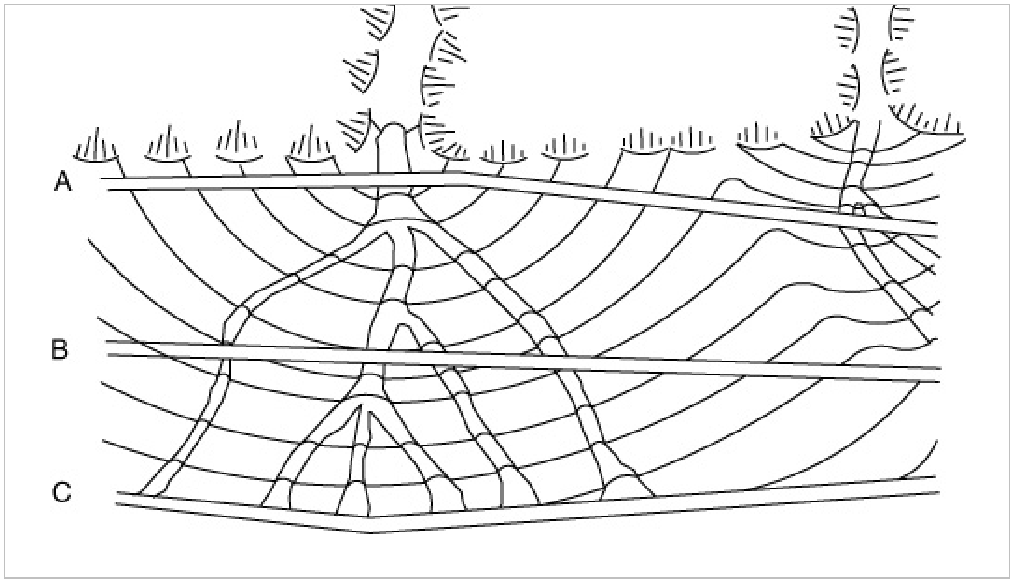


Figure 11-2. Possible Highway Alignments across an Alluvial Fan (Caltrans HDM Figure 872.3).

11.5 Wildfire and Debris Flows

Post-fire debris flows generally are triggered by one of two processes: surface erosion caused by rainfall runoff, and landsliding caused by infiltration of rainfall into the ground. Runoff-dominated processes are by far the most common because fires typically reduce the infiltration capacity of soils, which increases runoff and erosion (USGS, 2005b). The focus of this section is on debris flow impacts due to wildfires, although some discussion also applies to increased water runoff following a fire.

Post-fire reports from Interagency Burn Area Emergency Response (BAER) teams were obtained and reviewed for the Pines Fire of 2002 (northeast San Diego County), Walker Fire of 2002 (northwest of Mono Lake), Grand Prix, Old, and Padua Fires of 2003 (San Bernardino and San Gabriel Mountains), and Hackberry and Wildhorse Fires of 2005 (Mojave National Preserve).

11.5.1 Fire Impacts

In forested areas, the major factor influencing runoff and erosion from burned hillslopes is the amount of disturbance to the material that protects the underlying mineral soil. The unburned forest floor consists of a litter layer (leaves, needles, fine twigs, etc.) and a duff layer (partially decomposed remnants of the material from the litter layer). These layers absorb rainfall, provide water storage, and obstruct the flow of water on hillslopes. The combustion process converts these layers into ash and charcoal particles, which seal soil pores and decrease the infiltration rate, thereby increasing potential runoff and erosion. When the charcoal and ash are removed from the hillslope by post-fire runoff or wind, the soil is left bare and susceptible to increased erosion and runoff. Although less litter, duff, and vegetation are present in the desert than in a forested environment, the same processes occur. However, the differences in infiltration and runoff between pre-fire and post-fire conditions are less in arid regions than in a forest because there is less ground fuel to burn in the desert (Martin, 2005).

Soil burn severity is a relative measure of change in a watershed that relates to the severity of the effects of the fire on soil hydrologic function (Interagency BAER Team, 2002). Classes of burn severity are high, moderate, low, and unburned. Sediment generated from moderate and high burn severity slopes has the potential to reach channels and be entrained in stream flow, causing bulked water flows during flood events. In general, the denser the pre-fire vegetation and the longer the fire residence time, the more severe the effects of the fire are on soil hydrologic function. This is because fire promotes the formation of water repellent layers at or near the soil surface, and the loss of soil structural stability, both of which result in increased runoff and erosion (Interagency BAER Team, 2002). This water repellency, or hydrophobicity, is generally broken up or washed away within one or two years after a fire (Martin, 2005).

For the Walker Fire, the majority of the high burn severity areas were on very steep slopes and/or on areas with a high surface gravel, cobble, and stone content, which effectively mulch the soil surface (USFS, 2002). High burn severity led to localized water repellent conditions while removing the overstory vegetation and organic cover. A post-fire rainfall-runoff event led to a "tremendous" debris flow that overwhelmed the Highway 395 culvert at Tollhouse Canyon, spilling huge volumes across and along the highway and into the West Walker River (Lucich, 2002).

11.5.2 Desert Vegetation

The impact of wildfires on watershed runoff and sediment yield tends to be much less significant in desert areas than it is in forested, mountainous watersheds. A post-fire evaluation of the Hackberry and Wildhorse fires in the Mojave National Preserve found that although the fire intensity varied throughout the burn area, "the rapid rate of fire spread through the predominately fine fuels with light fuel loading, produced short fire residence times" (Martin, 2005). As a result, the burn severity with respect to the soil was low throughout most of the burn area, with some areas of moderate burn severity. The low-to-moderate soil burn severity was not expected to cause a significant post-fire increase in runoff or erosion. Figure 11-3 and Figure 11-4 show examples of low and moderate soil burn severity, respectively in the Mojave National Preserve.

Creosote bush scrub, succulent scrub, and alkali sink vegetation all have typically low surface fuel loads and continuity. However, some desert vegetation types can provide high fuel loads. These include pinyon-juniper woodlands, sagebrush scrub, and desert chaparral, and in some cases Joshua tree woodland as well as other types of desert scrub (Mojave National Preserve, 2004). For the Hackberry fire, high burn soil severity was limited to small, but dense stands of pinyon pine and juniper, under which deep layers of litter and duff had accumulated (Martin, 2005).

Prior to the Hackberry fire in the Mojave National Preserve, sparse vegetation, rocky slopes, and shallow soils resulted in very flashy stream flows, which carried sand, sediment, plants, large rocks, and other debris, in response to rainfall events. According to Martin (2005), these debris-laden flash floods would continue to occur with very little difference from pre-fire conditions.

Sediment/debris yield approaches that place a major emphasis on wildfire impacts based on steep, densely-forested watersheds would be less appropriate for the lower-density vegetation typical of California's desert areas. However, they may apply to the desert-draining watersheds located along the Transverse Ranges (San Gabriel and San Bernardino Mountains) and the Peninsular Ranges (San Jacinto, Santa Rosa, and Laguna Mountains).

Figure 11-3. Example of Low Soil Burn Severity (Martin, 2005).

Figure 11-4. Example of Moderate Soil Burn Severity (Martin, 2005).

11.6 Agency Methods

Described below are sediment/debris bulking factors and procedures used by southern California counties (San Bernardino County, Los Angeles County, and Riverside County), the Los Angeles District of the U.S. Army Corps of Engineers, FEMA, and the Interagency Burned Area Emergency Response (BAER) Team. Manuals from other agencies, including Maricopa County (AZ), were consulted; however, they did not provide any additional guidance on the selection of bulking factors.

11.6.1 San Bernardino County

Some jurisdictions use a set value for bulking without conducting a detailed analysis for an individual watershed. The San Bernardino Flood Control District specifies a set bulking factor of 2 (i.e., 100% bulking) for any project where bulking of flows is anticipated. A bulking factor of 2 is equivalent to 50-percent sediment concentration by volume, which is approximately the upper limit for debris flows. Above this limit would generally be considered a landslide rather than a debris flow (see Table 11-1).

11.6.2 Los Angeles County

Other jurisdictions – including Los Angeles County and Riverside County – use a watershed-specific bulking factor.

The Los Angeles County Sedimentation Manual divides the County into three overall basins: Los Angeles Basin, Santa Clara River Basin, and Antelope Valley (Los Angeles County, 2006b). Only the Antelope Valley is located within our desert study area. Sediment production is dependent upon many factors including rainfall intensity, geology, soil type, vegetative coverage, runoff, and watershed slope. Within each basin, Debris Potential Area (DPA) zones have been delineated that yield similar volumes of sediment under similar conditions.

The Design Debris Event (DDE) is defined as the quantity of sediment produced by a saturated watershed significantly recovered from a burn (i.e., after four years) as a result of a 50-year, 24-hour rainfall amount. A rate of 120,000 cu.yd./mi^2 (74.4 acre-ft/mi^2) for the design storm has been established as the Design Debris Event for a one square-mile drainage area in the DPA 1 zone. This rate is used in areas of high relief and granitic formations that characterize the San Gabriel Mountains. Other mountain areas in the County have been assigned relatively lower sediment potentials based on historical data and differences in topography, geology, and rainfall. Sediment records indicate that areas less than one square-mile are expected to produce a higher rate of sediment production and areas greater than one square-mile, a lower rate. The Antelope Valley has eight debris production curves, as shown in Figure 11-5. These curves are for undeveloped watersheds.

The Los Angeles County Sedimentation Manual also provides a series of peak bulking factor curves. The peak bulking factor is estimated using the curves based on the watershed area and the DPA within which the watershed is located. Peak bulking factor curves for the Antelope Valley are shown in Figure 11-6. The maximum peak bulking factor ranges from approximately 1.02 (2% bulking) for DPA Zone 11 to 2.0 (100% bulking) for DPA Zone 1. The Los Angeles County procedure specifies a bulking factor for all areas, even where sediment concentrations and the resulting bulking factor are low.

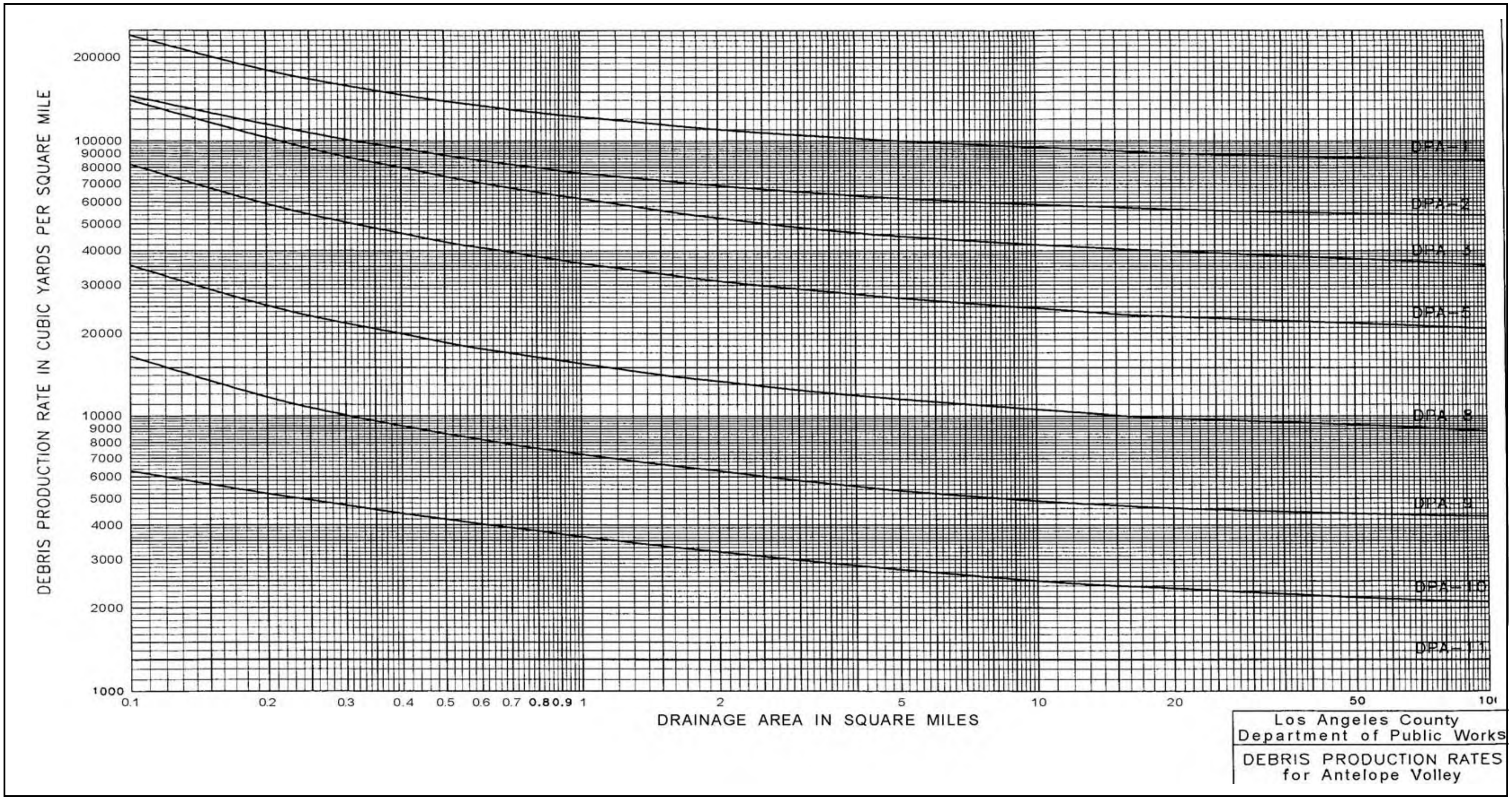


Figure 11-5. Debris Production Rates for Antelope Valley (Los Angeles County, 2006b).

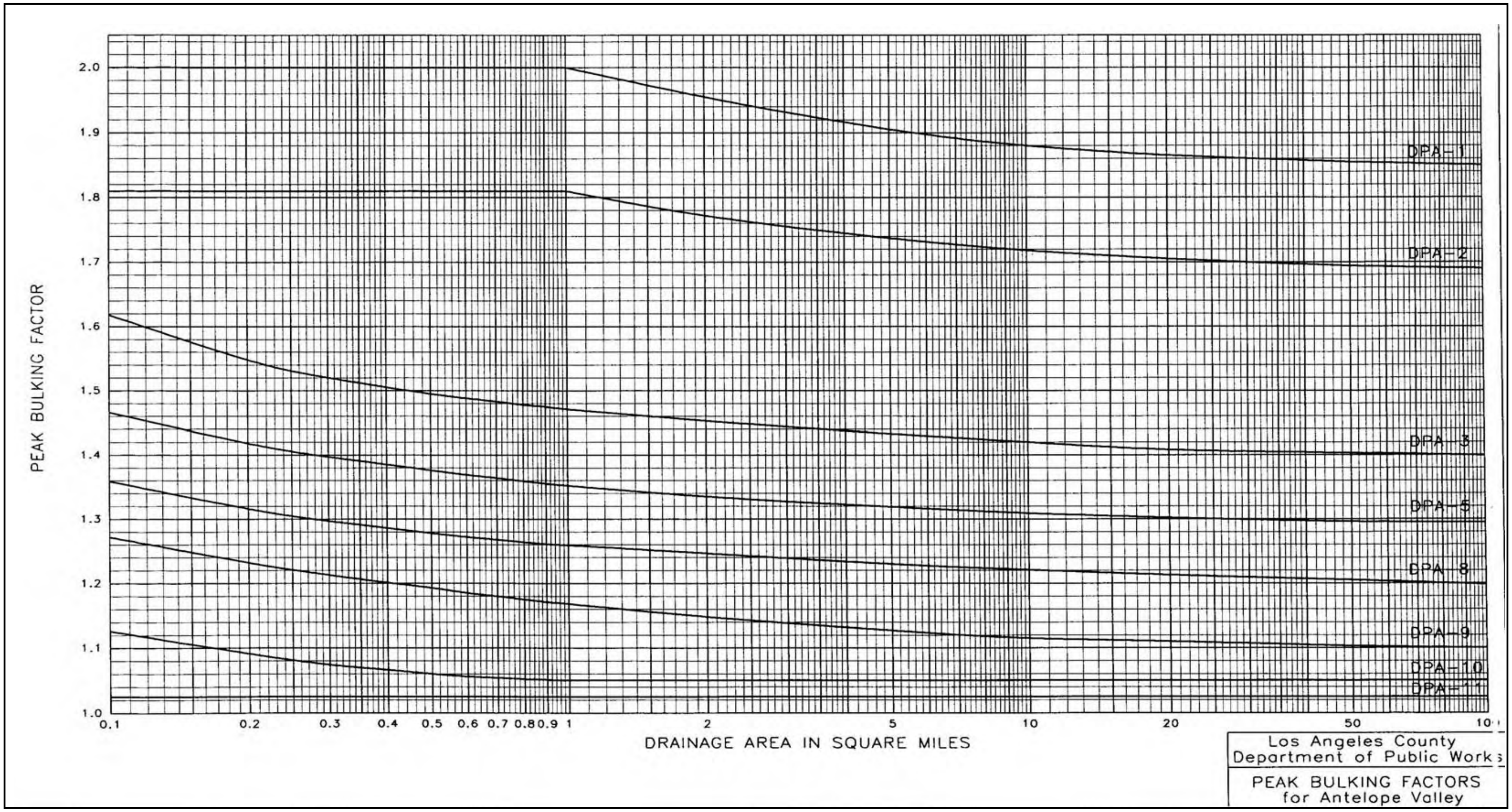


Figure 11-6. Peak Bulking Factors for Antelope Valley (Los Angeles County, 2006b).

11.6.3 Riverside County

The bulking factor in Riverside County is determined by estimating sediment/debris yield for a single event and comparing it to the largest expected sediment yield for a one square-mile watershed based on Los Angeles County procedures. The 120,000 cu.yd./mi^2 (74.4 acre-ft/mi^2) sediment yield, which is based on the debris production curve for Los Angeles County DPA Zone 1, is assumed to correspond to the largest expected bulking factor of 2.0.

As described in the Riverside County Hydrology Manual (1978), the peak bulking rate is computed as follows:

$$BF = 1 + \frac{D}{120{,}000} \qquad (11.5)$$

where *BF* is the bulking factor and *D* is the design storm sediment/debris production rate for the study watershed (cu.yd./mi^2).

11.6.4 Corps of Engineers – Los Angeles District Method

The Los Angeles District Method (U.S. Army Corps of Engineers, 2000a) was developed to estimate unit sediment/debris yield values for "n-year" flood events for the design and analysis of debris-catching structures in coastal Southern California watersheds, considering the coincident frequency of wildfire and flood magnitude. While the Los Angeles District method is for coastal-draining watersheds, it can also be used for the desert-draining watershed of these same local mountains.

The method is applicable to watersheds with an area of 0.1 to 200 mi^2, and for watersheds with a high proportion of their total area in steep, mountainous terrain. Best results will be obtained for watersheds that have undergone significant antecedent rainfall. In most cases, this antecedent rainfall condition will be satisfied when the watershed has received at least 2 inches of prior rainfall in approximately 48 hours. As a result, this method is more applicable to rainfall from general storms versus thunderstorms.

The method specifies several equations to estimate unit debris yield depending on the areal size of the watershed. These equations were developed by multiple regression analysis on sediment/debris data. As an example, for watersheds from 3 mi^2 to 10 mi^2 in area, the following predictive equation is used:

$$\log Dy = 0.85 \log Q + 0.53 \log RR + 0.04 \log A + 0.22 FF \qquad (11.6)$$

where:

Dy is the unit debris yield (yd^3/mi^2).

RR is the relief ratio (ft/mi) – difference in elevation between highest and lowest points on the longest watercourse divided by the length of the longest watercourse.

A is the drainage area (acres).

FF is the non-dimensional fire factor.

Q is the unit peak runoff (cfs/mi^2).

The non-dimensional fire factor *FF* accounts for increase in debris yield due to fire in the watershed. This factor varies between 3.0 and 6.5, with a higher factor indicating a more recent fire and higher debris yield. The factor is 3.0 (lowest) after 10 years without fire in a small watershed (basin area < 3.0 mi^2), and after 15 years without fire in relatively large watershed (basin area ≥ 3.0 mi^2.) This factor is also 3.0 for desert watersheds where the effect of wildfire is minimal. The Los Angeles District Method provides a graph of *FF* with drainage area and years after fire.

An Adjustment and Transposition (A-T) factor is applied to debris yield estimate to transpose the debris yield from the San Gabriel Mountains (from which the data were taken to develop the regression equations) to the study watershed. Areas with less debris yield potential than the San Gabriel Mountains would have A-T factors less than 1.0. Four techniques are available to estimate this factor, depending on the level of data available (see U.S. Army Corps of Engineers, 2000a).

Outside of the area from which the data were collected and used to develop the method (San Gabriel Mountains), the A-T Factor must be carefully applied. According to U.S. Army Corps of Engineers (2000a), "because vegetation types and density are far different in desert-draining [watersheds] than coastal-draining watersheds," the effects of wildfire on debris yield will not be the same. Therefore, the Fire Factor (FF) must also be used with a great deal of caution. Using this method for watersheds with a high percentage of alluvial fan or valley fill areas may result in yield estimates higher than would actually be produced by the watershed.

To convert the estimated debris yield (i.e., debris volume) to a bulking factor requires that the clear water hydrograph be computed using a rainfall-runoff model (e.g. HEC-HMS). To distribute the total debris volume throughout the flow hydrograph, the following equation is recommended:

$$Q_S = a\, Q_W{}^n \tag{11.7}$$

where Q_S is the sediment discharge (cfs), Q_W is the clear water discharge (cfs), and *a* and *n* are bulking constants (fixed throughout the hydrograph). According to Vanoni (2006), the value of *n* is between 2 and 3 for most sand-bed streams. Combining Equation 11.7 with 11.2 yields:

$$BF = \frac{Q_W + Q_S}{Q_W} = 1 + a\, Q_W^{n-1} \tag{11.8}$$

For $n = 2$, the bulking factor is linearly proportional to the clear water discharge. The coefficient *a* is determined by numerical integration of the squared 100-yr hydrograph ordinates as follows:

$$a = \frac{V_S}{\Delta t \sum Q_W^2} \tag{11.9}$$

where V_S is the total sediment yield and Δt is the computational time interval from the hydrologic model.

11.6.5 FEMA Post-fire Assessment

As part of FEMA's effort to assess the 2003 post-fire flood hazards, a number of flooding sources throughout San Diego, San Bernardino, Riverside, Ventura, and Los Angeles Counties were identified for analysis. Based upon past experience and engineering judgment, FEMA (2003c) used the bulking factors shown in Table 11-2 for their rapid post-fire assessment.

Table 11-2. Post-fire Bulking Factors used for 2003 Southern California Fires (FEMA, 2003c).

A (sq miles)	5-yr Discharge	100-yr Discharge
0-3	1.5	1.4
3-10	1.3	1.2
Above 10	1.2	1.1

Two key points from this table are (1) bulking factor decreases as the drainage area increases, and (2) bulking factor decreases as the recurrence interval increases from a 5-year to 100-year recurrence interval.

11.6.6 Interagency BAER Team

In their post-fire assessment of the Pines Fire, the Interagency Burned Area Emergency Response (BAER) Team (2002) describes their method for determining the bulked discharge.

The bulked discharge, Q_B, is defined as:

$$Q_B = Q_{\text{pre-fire}} + Q_{\text{pre-fire}}(\%\text{HighBurn}*0.7 + \%\text{ModerateBurn}*0.5 + \%\text{LowBurn}*0.2) \quad (11.10)$$

where $Q_{\text{pre-fire}}$ is the peak discharge before the burn, %HighBurn is the percentage of the watershed with high soil burn severity, %ModerateBurn is the percentage of the watershed with moderate soil burn severity, and %LowBurn is the percentage of the watershed with low soil burn severity, all entered as fractions in the equation above (e.g., 0.25 instead of 25%). Note: These three soil burn severity percentages may not necessarily add up to 1 (or 100%) since a portion of the watershed may have been left unburned. Conversion of Equation 11.10 to a bulking factor yields:

$$BF = 1 + \%\text{HighBurn}*0.7 + \%\text{ModerateBurn}*0.5 + \%\text{LowBurn}*0.2 \quad (11.11)$$

The maximum bulking factor that can be obtained using this equation is 1.7, which occurs when the entire watershed has a high soil burn severity. Equation 11.11 has less application for design purposes because it is intended for use immediately after a fire occurs.

11.7 Recommended Approach

While the bulking factor can be defined as a function of the sediment concentration, the expected concentration during a major flood event can only be estimated with significant uncertainty. As a result, the bulking factor should generally be considered a safety factor selected based on a combination of watershed data and engineering judgment, rather than a strictly computed value.

The bulking potential depends on the type of sediment-laden flow expected in the watershed, which may be determined by field reconnaissance, data collection, and consultation with local, State, and Federal agencies. Based on the information collected, engineering judgment and geomorphic experience should then be used to determine an appropriate bulking factor for the project. For hydraulic design, the main purpose of using bulked flows is to introduce a factor of safety when computing the required bridge opening or channel dimensions. Therefore, the selected bulking factor may not be strictly based on the expected maximum sediment concentration in the flow.

For watersheds originating in the Transverse Ranges, including the San Gabriel and San Bernardino Mountains, the Los Angeles District Method can be used. For sites within Los Angeles County, any computed values can be compared with the bulking factor curves provided in the Los Angeles County Sedimentation Manual (2006). The Los Angeles District Method can also be used for Peninsular Ranges, including the San Jacinto, Santa Rosa, and Laguna Mountains; however, the Adjustment-Transposition (A-T) factor must be used with caution and sediment volumes would tend to be overestimated using this method in these areas.

Bulking factors should be applied with a degree of caution where the discharge has been computed based on stream gage data because the gage data could reflect some bulking due to sediment/debris. With that said, if a significant debris-laden flow had actually occurred upstream of a stream gage, it is likely that the stream gage would have been severely damaged or destroyed, so the event would not have been recorded. Therefore, peak discharges in the stream gage record are not likely to include significant bulked conditions.

A flow chart outlining the recommended bulking factor selection process is provided as Figure 11-7. Data sources are provided in Appendix E.

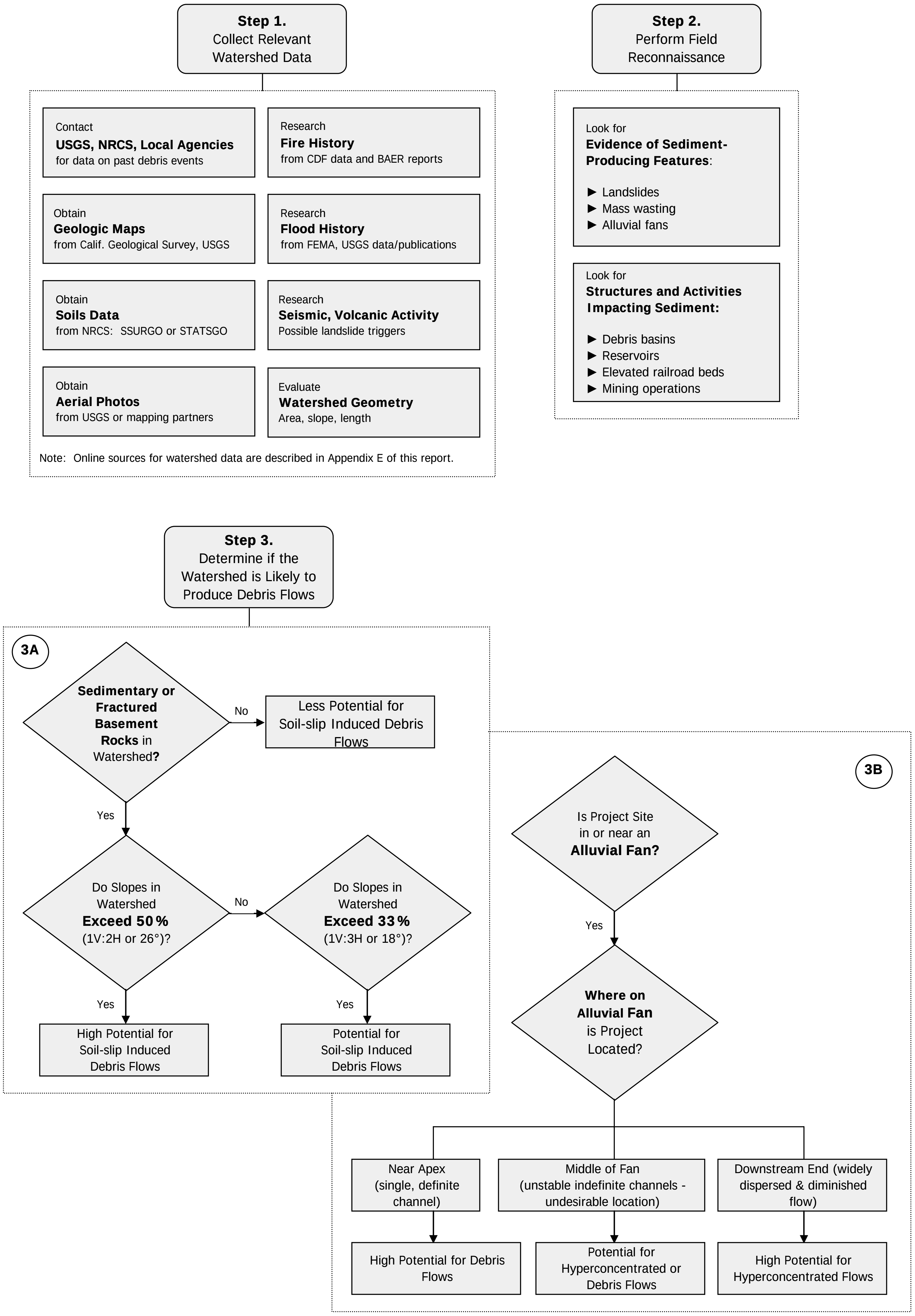


Figure 11-7. Bulking Factor Flowchart, Part 1 of 2.

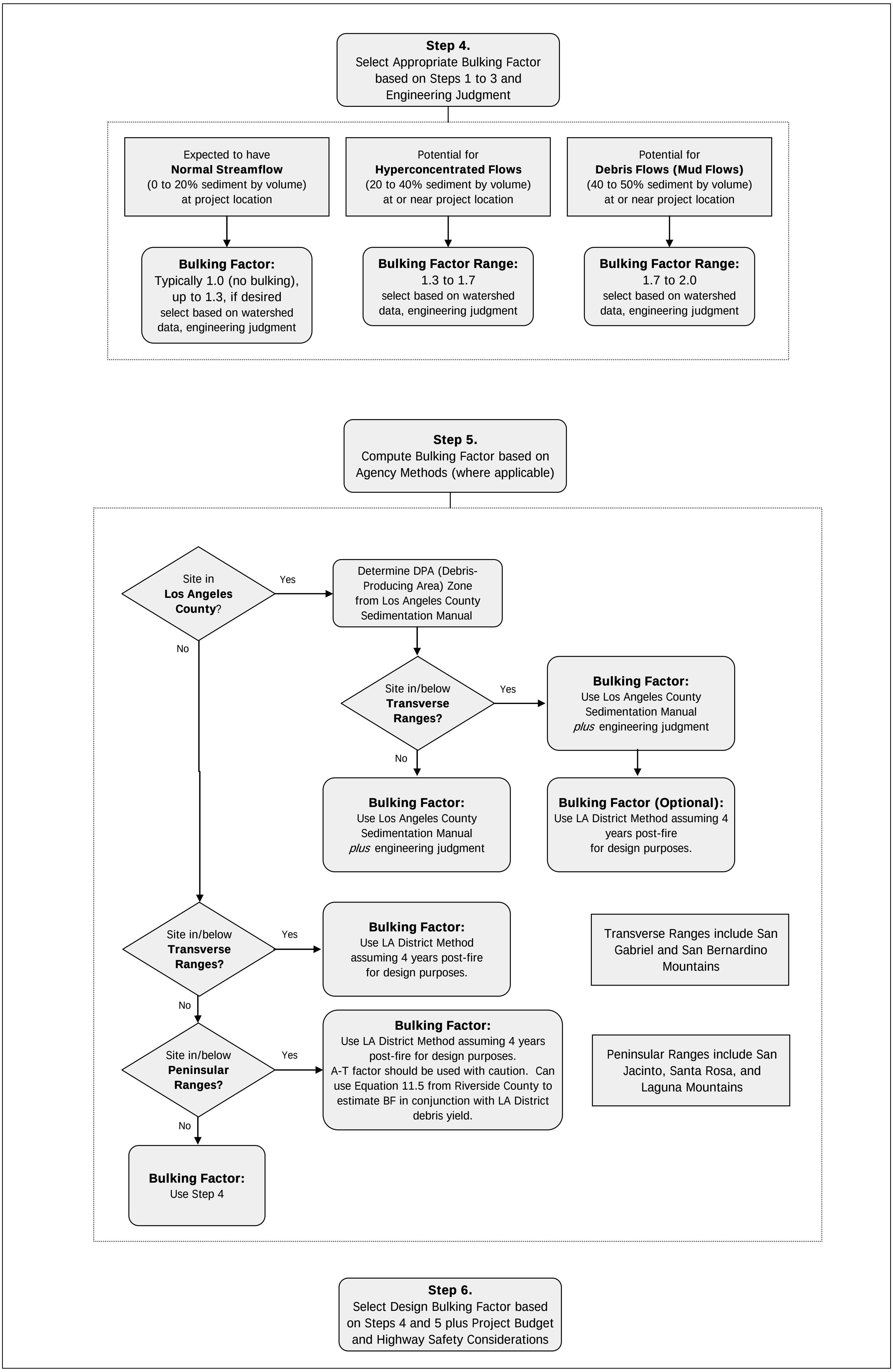


Figure 11-8. Bulking Factor Flowchart, Part 2 of 2.

11.8 Example Application – Borrego Palm Canyon

Although no sediment data were available to validate the selection of bulking factors, the Borrego Palm Canyon watershed was used to illustrate use of the bulking factor flow chart.

11.8.1 Geologic Conditions

According to the Interagency BAER report, the watershed is characterized by "high relief and very steep slopes with narrow canyon bottoms and outwash alluvial fans." Bedrock geology consists of two principal rock types: metamorphosed sedimentary rocks and granitic rocks, which weather into large boulders in a matrix of decomposing granite (DG). Surficial deposits include unconsolidated alluvium, colluvium, and debris-flow deposits.

11.8.2 Wildfire

According to Interagency BAER Team (2002), "increased runoff due to post-fire changes in hydrologic response within the burned area can mobilize much larger volumes of sediment from DG slopes than from soils formed in other geology." Significant recorded fires (ranked from largest to smallest affected area) occurred in the Borrego Palm Canyon watershed in 2002, 1954, 1939, and 1975. The Pines Fire of 2002 burned over 90 percent of the Borrego Palm Canyon watershed, with primarily low and moderate soil burn severity (Interagency BAER Team, 2002).

11.8.3 Alluvial Fan

An alluvial fan is located at the downstream end of the Borrego Palm Canyon watershed, as shown on an alluvial fan flooding map developed for the Borrego Valley (see Figure 11-9).

11.8.4 Bulking Factor

Following the bulking factor flow chart (Figure 11-7), and given the presence of this alluvial fan, as well as the history of fire in the watershed, a high bulking factor in the range of 1.7 to 2.0 would be recommended.

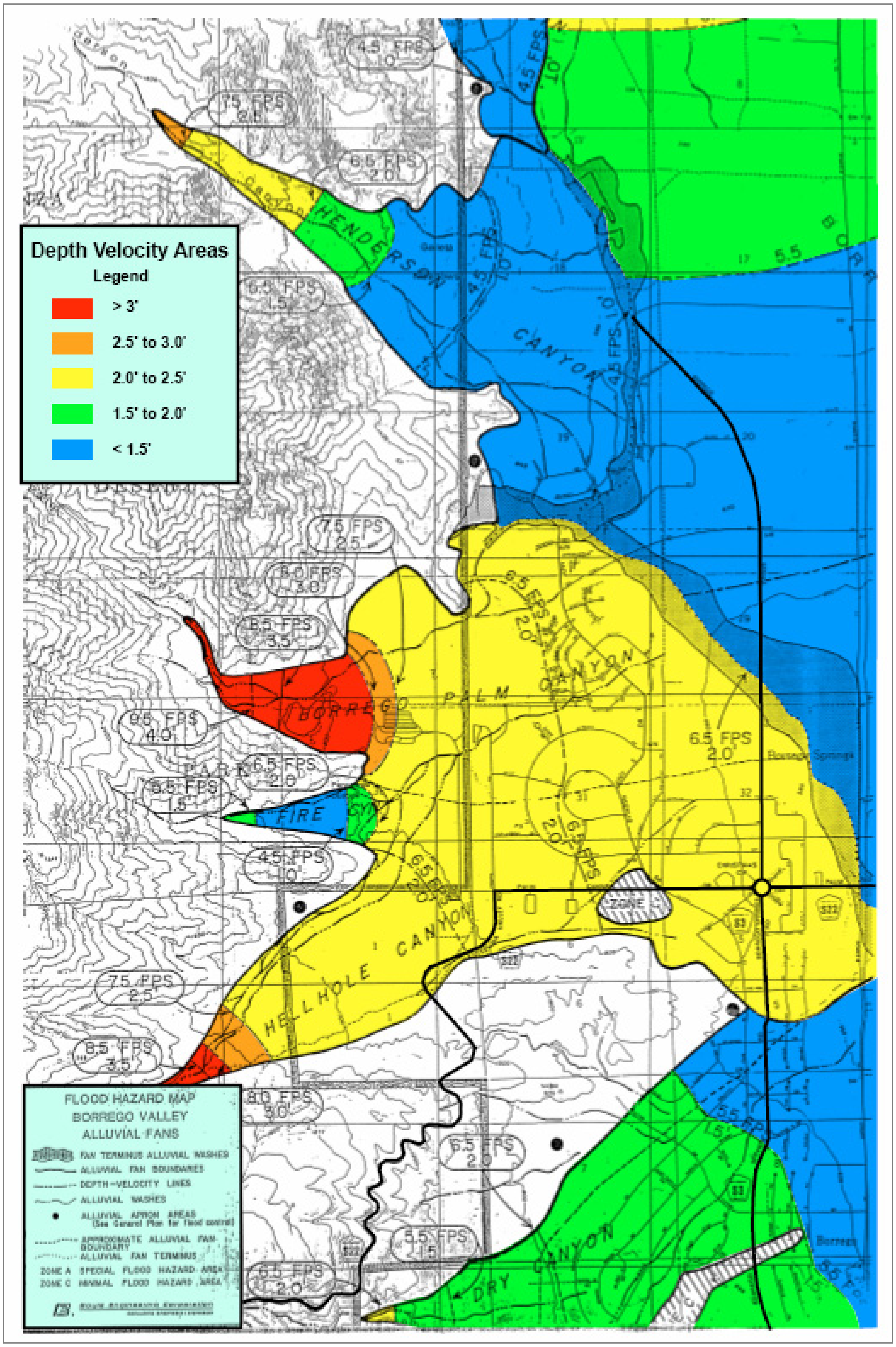


Figure 11-9. Borrego Valley Alluvial Fans – Flood Hazard Map (Boyle Engineering, 1989).

12 SUMMARY AND CONCLUSION

Provided in this chapter is a summary of the work completed for the desert hydrology study, as well its major findings.

12.1 Literature Review

In the first phase of the study, hydrologic and sediment/debris methods used by local, state, and Federal agencies in the desert environments of California, Nevada, Arizona, and New Mexico were investigated. Interviews were then conducted with qualified agency personnel. In particular, Caltrans District hydrologists or hydraulic engineers were contacted to see what guidance is currently being used for hydrologic design.

12.2 Desert Regions

California's desert areas were divided into six regions based on similar geographic, climatic, and hydrologic characteristics:

1. Colorado Desert – includes Imperial Valley, Salton Sea, and Coachella Valley
2. Sonoran Desert – located southeast of the Mojave Desert region
3. Antelope Valley – located primarily in Los Angeles and Kern Counties
4. Mojave Desert – largest region, includes Mojave Valley and Death Valley
5. Owens Valley/Mono Lake – arid region on the leeward side of the Sierra Nevada
6. Northern Basin & Range – cold desert of northeastern California

Geospatial data used to develop the desert region boundaries included hydrologic/watershed and regional flood frequency boundaries; ecologic regions; topographic, vegetation, and soils data; and climatic data (precipitation, temperature).

12.3 Desert Storms

Basic types of storms that can occur over California's desert regions are often classified as general winter storms, local thunderstorms, and general summer storms. General storms are usually of a frontal or convergence type that covers large areas (a front is a zone that separates two air masses, one of which is cooler than the other). Local storms are usually associated with convective activities and normally occur in the summer (convection is the vertical transport of heat and moisture in the atmosphere, typically caused by an unstable atmosphere).

Annual peak flow data at USGS stream-gaging stations within the six desert regions were analyzed for the season in which each annual peak occurred. The evaluation of the areal and seasonal distributions of peak flow population and the associated storm types clearly indicate that there are two distinct regions in California's semi-arid and arid areas, each of which has a different dominant precipitation pattern. In the southern desert area, summer convective storms (thunderstorms) are generally dominant. In the northern part, general winter storms are the primary climatic factor that causes floods.

12.4 Flood Frequency Analysis

Although there are not many long records of annual peak flow data in the desert regions, the records represent valuable observed flood conditions for desert basins with a high variability in storms, soil conditions, and land use. Therefore, efforts should be made to make the maximum use of the observed data where available. There are two main USGS reports that include flood-frequency flows for many stations in the desert areas: Water Supply Paper (WSP) 2433 – *Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States* and Water Resources Investigations (WRI) 77-21 – *Magnitude and Frequency of Foods in California*.

The following methods are recommended for flood-frequency analysis:

- If there are two gaged sites with similar watershed characteristics but one has a short record and the other has a longer record of peak flows, a two-station comparison analysis can be conducted to extend the equivalent length of record at the shorter gaged site.

- Flood-frequency relations at sites near gaged sites on the same stream (or in a similar watershed) can be estimated using a ratio of drainage area for the ungaged and gaged sites.

- At a gaged site, weighted estimates of peak discharges based on the station flood-frequency relation and the regional regression equations are considered the best estimates of flood frequency and are used to reduce the time-sampling error that may occur in a station flood-frequency estimate.

- The flood-frequency flows and the maximum peak discharges at several stations in a region should be used whenever possible for comparison with the peak discharge estimated at an ungaged site using a rainfall-runoff approach or regional regression equation. The watershed characteristics at the ungaged and gaged sites should be similar.

12.5 Regional Regression

The current regional regression equations in USGS publications WSP 2433 and WRI 77-21 were found to be not representative of the watershed conditions in our desert study area. For this reason, the data set that was used to develop the USGS regression equations was reduced to a subset such that all selected stations have watershed characteristics similar to California's desert regions. New regression equations were then developed from the reduced data set. These equations can provide a good check on the reasonableness of peak discharges computed using rainfall-runoff simulation for an ungaged watershed.

One set of regional regression equations was developed for the southern desert regions (Colorado Desert, Sonoran Desert, Mojave Desert, and the Antelope Valley) based on a hybrid regional regression analysis, the same method used in WSP 2433 for Region 10. These equations were found to predict flows better than the WSP 2433 equations for these regions.

For the Owens Valley/Mono Lake region, a new set of regional regression equations was developed using standard regression analyses with a subset of data from WSP 2433 Regions 5 and 6. The coefficients of determination (r^2) for the new regression equations range from average to very good (0.52 to 0.83). In general, the new equations for this region provide better flow estimates than the WSP 2433 Region 5 regression equations.

For the Northern Basin and Range, a combination of data from WSP 2433 Region 2 and WRI 77-21 Northeast Region was used to develop new regression equations. While the newly developed regression equations predict flows better than the USGS regression equations, the coefficients of determination (r^2) are low. Therefore, there is significant uncertainty associated with the new regression equations for the Northern Basin and Range, and the development of a rainfall-runoff model may be preferable for ungaged watersheds in this region.

12.6 Rational Method

Given the assumptions of the Rational Method, an approximate upper limit of 160 acres (0.25 mi^2) is recommended for California's desert regions. Although this limit is approximate in nature, strong consideration should be given to selecting another more appropriate hydrologic method if the drainage area approaches or exceeds 160 acres.

Rainfall intensity-duration-frequency data used for the Rational Method can be obtained from either NOAA Atlas 14 (preferred where available) or DWR Bulletin No. 195. Runoff coefficients were provided for a number of typical desert terrain/vegetation types.

12.7 Rainfall-Runoff Simulation

For the southern portion of California's desert areas (Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert regions) the critical flood-producing storm is the local thunderstorm with durations generally less than 6 hours. Review of the largest historical peaks in southern California indicates that most of these peaks occurred in small watersheds with drainage areas less than 20 square miles. A storm of 6-hour duration will account for almost all of the volume produced by summer thunderstorms. These 6-hour design storms contain intense rainfall for the shorter durations as well, so that they also represent the critical storms in producing peak discharges.

For drainage areas between 20 and 100 square miles, the critical storm could be a local thunderstorm or a general storm, as either could produce the greatest flood peak discharges or the maximum flood volumes. Therefore, it is necessary to consider both general storms and local storms. A general storm usually covers a larger area and has a longer duration. A 24-hour general storm is often selected. For drainage areas larger than 100 square miles, a general storm typically produces the largest peak discharge and runoff volumes. For the northern portion of the study area, which includes the Owens Valley/Mono Lake and Northern Basin and Range regions, a general winter storm is typically dominant. Therefore, the design storm should be the 24-hour general storm. There are no drainage area restrictions; the general storm is used for all watersheds in the northern regions.

NOAA has published updated precipitation-frequency estimates for Arizona, Nevada, New Mexico, Utah, and southeastern California (Imperial, Inyo, eastern Kern, eastern Los Angeles, Riverside, San

Bernardino, and eastern San Diego counties), often cited as NOAA Atlas 14. NOAA Atlas 14 now supersedes information contained in NOAA Atlas 2 and other publications. The atlas provides precipitation frequency estimates for 5-minute through 60-day durations at average recurrence intervals of 2 years through 1,000 years. The results are provided at high spatial resolution and include confidence limits for the estimate. Bulletin No. 195 (California Department of Water Resources, 1976; with periodic updates since 1976) is often used by Caltrans engineers to obtain depth-duration-frequency data for watersheds in California. The Pearson Type III distribution is used in Bulletin No. 195 to model all storm durations. For desert regions, the use of NOAA Atlas 14 is recommended over Bulletin No. 195 because the NOAA National Weather Service used a state-of-the-art L-moment approach rather than using only the Pearson Type III distribution. However, the use of Bulletin No. 195 is acceptable where NOAA Atlas 14 data are not available.

There is a general consensus among hydrometeorologists that for the southwestern United States, the depth-area curves from NWS HYDRO-40 are more representative of desert thunderstorm conditions than are the curves from the earlier NOAA Atlas 2. Therefore, the depth-area curve from NWS HYDRO-40 is recommended for use in the southern desert regions (Colorado Desert, Sonoran Desert, Antelope Valley, and Mojave Desert). The curve from NOAA Atlas 2 is recommended for the northern regions (Owens Valley/Mono Lake and Northern Basin and Range) as it better characterizes the spatial distribution of general storm rainfall.

Seven watersheds were selected to test the rainfall-runoff methods believed to be the most applicable to California's desert regions. Test watersheds for each desert region were selected based on the availability of nearby peak streamflow gage(s) and hourly precipitation station(s) with overlapping periods of record, and one or more peak streamflow events occurring during the overlapping period of record. Preference was given to watersheds where a precipitation gage was located in the upper portion of the watershed, and where the creek/wash can impact a road or highway.

The selected test watersheds are listed below.

Desert Region	**Watershed Name**	**Watershed Area (mi^2)**
Region 1 – Colorado Desert	Borrego Palm Canyon	21.8
Region 2 – Sonoran Desert	Monument Wash	4.3
Region 3 – Antelope Valley	Big Rock Wash	34.2
Region 4 – Mojave Desert (Site 1)	West Fork Mojave River	3.2
Region 4 – Mojave Desert (Site 2)	Fortynine Palms Creek	8.5
Region 5 – Owens Valley/Mono Lake	Independence Creek	18.1
Region 6 – Northern Basin and Range	Mill Creek	2.1

After the model parameters were selected and recorded rainfall-runoff events were simulated, each hydrologic model was then used to simulate a synthetic design storm to compute the 100-year peak discharge. The approach taken in the rainfall-runoff simulation was to treat the test watersheds as if they were ungaged, with the selection of appropriate model parameters based on readily available data for the watershed rather than performing true model calibration. Instead of calibration, the applicability of the hydrologic methods and parameters was validated by comparing rainfall-runoff computed flows to either observed values or those computed by flood-frequency analysis or using the new regional regression equations.

A summary of the major findings from the rainfall-runoff simulation are provided below.

Infiltration Methods

- The SCS Curve Number and Green and Ampt infiltration methods were analyzed.
- The Green and Ampt method greatly overestimated infiltration losses for the majority of test watersheds where it was applied, resulting in zero flow values in some cases.
- The SCS Curve Number method provided favorable results for the majority of test watersheds and is recommended for use by Caltrans for desert hydrology studies.

Transformation Methods

- Four S-Graphs were analyzed: San Bernardino County Desert S-Graph, San Bernardino County Mountain S-Graph, Maricopa County Desert/Rangeland S-Graph, and USBR S-Graph.
- The San Bernardino County Mountain S-Graph is recommended for watersheds with mountainous terrain/high elevations in the upper portions.
- Simulation results using the San Bernardino County Desert S-Graph and Maricopa County Desert/Rangeland S-Graph were comparable.
- For the sake of consistency, the San Bernardino County Desert S-Graph is recommended for use in watersheds in the southern desert regions with limited or no mountainous terrain/high elevations.
- The USBR (1987) S-Graph is recommended for watersheds in the Northern Basin and Range.

Antecedent Moisture Condition

- Two Antecedent Moisture Conditions were analyzed for the recorded rainfall events: AMC I and AMC II. The differences in AMC I vs. AMC II are reflected in the SCS curve numbers.
- AMC I was analyzed for test watersheds in the southern desert regions. AMC II was analyzed for test watershed southern desert regions greater than 20 square miles and the Northern Basin and Range.
- AMC I provided the best results for watersheds in the southern desert region, including those over 20 square miles.
- AMC II provided favorable results for the test watershed in the Northern Basin and Range region.

Storm Duration and Temporal Distribution

- Two storm duration/temporal distributions were analyzed: 100-year, 6-hour Convective Storm (AMC I) and 100-year, 24-hour General Storm (AMC II).
    - The 100-year, 6-hour Convective Storm with AMC I was analyzed for test watersheds in the southern desert regions.
    - The 100-year, 24-hour General Storm with AMC II was analyzed for test watersheds exceeding 20 square miles in the southern desert regions and the test watershed in the Northern Basin and Range region.
- For watersheds in the southern desert regions with a drainage area *less than* 20 square miles, the 100-year, 6-hour Convective Storm (AMC I) provided favorable results and is recommended for use by Caltrans in estimating the 100-year peak discharge or other large flows.
- For the two watersheds in the southern desert regions with a drainage area *greater than* 20 square miles (Borrego Palm Canyon and Big Rock Wash), the results were mixed.
    - The 100-year, 6-hour Convective Storm (AMC I) provided the best results for Borrego Palm Canyon in the Colorado Desert region.
    - The 100-year, 24-hour General Storm (AMC II) provided the best results for the more mountainous Big Rock Wash watershed in the Antelope Valley region.
    - In each case, the storm that produced the largest peak discharge was also the one that provided the best results.
- For watersheds greater than 20 square miles in the southern desert regions, both the 6-hour Convective Storm (AMC I) and the 24-hour General Storm (AMC II) should be analyzed and the larger of the two peak discharges selected.
- Watersheds along the Eastern Sierra in the Owens Valley/Mono Lake region are dominated by snowmelt-driven peaks. The use of regional regression equations is recommended where streamgage data are not available; otherwise, hydrologic modeling could be performed with snowmelt simulation, which is beyond the scope of this study.
- For the Northern Basin and Range region, the 100-year, 24-hour General Storm (AMC II) provided favorable results and is recommended for use by Caltrans in estimating the 100-year peak discharge or other large flows.

Recommendations for desert hydrology, including those for flood-frequency analysis, regional regression, and rainfall-runoff simulation, are summarized in the hydrology flowchart.

12.8 Sediment/Debris Bulking

While the bulking factor can be defined as a function of the sediment concentration, the expected concentration during a major flood event can only be estimated with significant uncertainty. As a result, the bulking factor should generally be considered a safety factor selected based on a combination of watershed data and engineering judgment, rather than a strictly computed value.

The bulking potential depends on the type of sediment-laden flow expected in the watershed, which may be determined by field reconnaissance, data collection, and consultation with local, State, and Federal agencies. Based on the information collected, engineering judgment and geomorphic experience should then be used to determine an appropriate bulking factor for the project. For hydraulic design, the main purpose of using bulked flows is to introduce a factor of safety when computing the required bridge opening or channel dimensions. Therefore, the selected bulking factor may not be strictly based on the expected maximum sediment concentration in the flow.

A flow chart was developed that outlines the recommended bulking factor selection process.

12.9 Conclusion

A suite of desert-specific hydrologic methods have been developed that will help to improve flow estimates used in culvert, bridge, and channel design. These methods are intended to provide consistency in the estimation of desert hydrographs, bulking factors to reflect sediment and debris loads, and the subsequent flows used for sizing highway structures. With improved hydrologic methods as tools for project design, the engineer will have a basis for defending design and cost proposals to project managers, local agencies, and other interested parties.

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APPENDIX A

Phase I Research/Literature Review

Annotated Bibliography
Interviews with Agency Personnel

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1 *Title:* **Relation between Sediment Yield and Gradient on Debris-Covered Hillslopes, Walnut Gulch, Arizona**

Author: Abrahams, A.D., and Parsons, A.J.

Publication Date: August 1991

Publication Info: Geological Society of America Bulletin, Vol. 103, No. , pp. 1109-1113

Summary: The relation between overland-flow erosion and gradient on debris-covered semiarid hillslopes in Walnut Gulch Experimental Watershed, Arizona, is investigated by conducting three sets of field experiments under simulated rainfall on two different substrates. In all three sets of experiments, runoff is controlled by either stone cover or stone size, and stone size increases with gradient.

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2 *Title:* **Roadway Design Guidelines**

Chapter 600 - Highway Drainage Design

Author: ADOT

Publication Date: May 1996

Publication Info: Arizona DOT DOC 31-089

Summary: Determination of the design flow should be based upon the following sources, given in order of relative importance: 1) existing hydrologic studies, 2) gaging station records (flood frequency analysis), and 3) rainfall-runoff models.

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3 *Title:* **Prediction of Sediment Yield for Southern California Watersheds**

Water Forum '86

Author: Amar, A.C., Gatwood, E.J.

Publication Date: 1986

Publication Info: ASCE Conf. Proceedings

Summary: Multiple linear regression based sediment yield prediction equations are derived for Southern California Watersheds. A simplified approach is used where watershed erosion is not broken down into rill and interrill processes, and transport processes of detached sediment or deposition are not considered. Two regression equations, one for drainage area up to 3 sq. mi. and the other for drainage areas greater than 3 sq. mi. are developed. Both equations include a non-dimensional site-specific geomorphic/geologic adjustment factor. Without this adjustment factor, application of these regression equations in areas other than Southern California may lead to overestimation of sediment yield. The two equations differ in the availability of peak flow data, which was considered to be unavailable for watersheds less than 3 sq. mi.. Other regression parameters considered are drainage area, relief ratio, rainfall depth, and fire factor. All parameters were significant at 95% or more level of confidence.

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4 *Title:* **Requirements for Floodplain Delineation in Riverine Environments**

Author: Arizona Department of Water Resources

Publication Date: July 1996

Publication Info: Arizona Department of Water Resources Arizona State Standard 2-96

Summary: The intent of this document is to provide methodologies for estimating 100-year peak discharges, delineating 100-year floodplain limits, and determining administrative floodway boundaries for riverine floodplains in Arizona. Methodologies for non-riverine floodplain areas, such as alluvial fans, are not addressed. There are three levels, or methods, presented for determining the discharge. The Level 1 discharge methodology was derived from a published comprehensive analysis of stream gage records in the Southwest (USGS OFR 93-419). The methodology consists of an envelope curve constructed using the maximum discharges from Arizona and the Southwest gaged by the USGS. Because the methodology is based on an envelope curve, the peak discharge estimates tend to be conservative. For Level 2, equations for estimating peak discharges for ungaged watersheds in Arizona and the Southwest were developed by the USGS using stream gage records, regression analyses and a newly developed statistical procedure for arid regions. Unique equations were developed for each of seven regions within Arizona, including a region for watersheds at high elevation (> 7,500 feet). Required information includes the watershed area and may include one of the following: (1) mean annual precipitation, (2) mean elevation, or (3) mean annual evaporation. For Level 3, methods approved for use in hydrologic analyses include frequency/peak discharge estimation using the computer programs HEC-1 and TR-55, and TR-20 for synthetic peak discharge estimation. Where possible, any synthetic peak discharge estimation techniques should be calibrated to locally observed hydrologic conditions. Where stream gage records are available, flood frequency estimates can be made using statistical analysis.

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5 *Title:* **State Standard for Storm Water Detention/Retention**
Author: Arizona Department of Water Resources
Publication Date: August 1999
Publication Info: Arizona Department of Water Resources State Standard 8-99

Summary: The purpose of the project was to conduct a literature search and assessment of the practice of stormwater detention/retention in Arizona and the southwest, identify stormwater detention/retention methods and practices, and develop guidelines based on the information gathered. This report mostly utilizes the rational method.

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6 *Title:* **Short Duration Rainfall Relations for the Western United States**
A Critical Era
Author: Arkell, R.E., and Richards, F,
Publication Date: August 1986
Publication Info: Conference on Climate and Water Management

Summary: The paper presents results from short duration precipitation-frequency ratio development for 10 western states. The ratios relate 5-, 10-, 15-, and 30-minute precipitation-frequency amounts to 1-hour amounts from NOAA Atlas 2. The data from 61 stations used in the study were the largest annual precipitation amounts for 5-, 10-, 15-, 30-, and 60-minute durations. Frequency values were determined for all durations using Gumbel distribution. Standard deviations were larger in the southwest deserts than in the coastal northwest due to the difference between the sporadic summertime convective storms of the first region and the more regular wintertime stratiform character of the second. Regional ratios were derived by averaging the ratios over each region by weighting the individual stations by their length of record. The trends between regions, between durations, and between return periods were of primary interest for the study. Ratios derived in this report were found to be consistent with previous studies.

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7 *Title:* **Yavapai County Drainage Criteria Manual**
Author: Arroyo Engineering, LLC
Publication Date: August 2005
Publication Info: Yavapai County Development Services Flood Control District

Summary: Methodologies acceptable to Yavapai County for estimating peak discharges and developing synthetic hydrographs for use in the analysis and design of drainage facilities include the Rational Method and the U.S. Army Corps of Engineers HEC-1 Flood Hydrograph Package. The most current Arizona Department of Transportation (ADOT) Highway Drainage Manual should be used for guidance when utilizing the two methods.

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8 *Title:* **Application of Geological Information to Arizona Flood Hazard Assessment**
Hydraulics/Hydrology of Arid Lands (H2AL)
Author: Baker, V. R., Demsey, K. A., Ely, L. L., Fuller, J. E., House, P. K., O'Connor, J. E., Onken, J. A.
Publication Date: 1990
Publication Info: ASCE Conf. Proceedings

Summary: The importance of paleoflood hydrology analysis in alluvial fan flood hazard mapping is discussed. The research work documents how hydrological modeling procedures applied to regulatory flood-hazard zonation can be misapplied when assumptions concerning flood hazardous (geomorphic) processes are violated. The areas designated by FEMA as active alluvial fan under 100-year flooding may turn out not to be so using geomorphic mapping. The paper draws comparison between FEMA approach and geomorphic mapping to piedmont flood hazard from the point of view of paleoflood hydrology.

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9 *Title:* **Statistical Methods in Hydrology**
Author: Beard, L.R.
Publication Date: January 1962
Publication Info: U.S. Army Corps of Engineers, Hydrologic Engineering Center TD-4

Summary: This training document, published in 1962, stands out for its description and illustration of the application of statistics in hydrologic engineering, especially flood frequency analysis. The document covers the following topics: 1) review of the basic concepts of probability and correlation analyses; 2) presentation of detailed computation procedures and computation aids for derivation of frequency estimates based on analysis of hydrologic record; and 3) summary of procedures for developing “regionalized” hydrologic frequency estimates, based on analyses of hydrologic records available at stream gaging stations, adjusted to provide generalized flood-frequency relations that are considered to be representative of long-period hydrologic characteristics.

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10 *Title:* **Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States**
Author: Blakemore, E.T., Hjalmarson, H. W., Waltemeyer, S. D.
Publication Date: 1997
Publication Info: USGS Water Supply Paper 2433

Summary: Equations for estimating 2-, 5-, 10-, 25-, 50-, and 100-year peak discharges at ungaged sites in the southwestern United States were developed using generalized least-squares multiple-regression techniques and a hybrid method that was developed in this study. The equations are applicable to unregulated streams that drain basins of less than about 200 square miles. Drainage area, mean basin elevation, mean annual precipitation, mean annual evaporation, latitude, and longitude are the basin and climatic characteristics used in the equations. The study area was divided into 16 flood regions; Region 1 is a high-elevation region that includes the entire study area.

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11 *Title:* **Precipitation Depth-Duration and Frequency Characteristics for Antelope Valley, Mojave Desert, California**

Author: Blodgett, J.C.

Publication Date: 1995

Publication Info: USGS Water-Investigations Report 95-4056

Summary: Potential change in runoff volume from urbanization was studied on nine small basins that were considered representative of varying hydrologic conditions in Antelope Valley, California. The data collected at USGS stations were supplemented by data collected at 35 long-term precipitation stations operated by NOAA, and the Los Angeles County Department of Public Works. These data were to be used to calibrate and verify rainfall-runoff models for the nine basins. Depth-duration ratios were calculated by disaggregating daily total precipitation data for intervals of 1, 2, 3, 4, 5 6, 12, and 18 hours for storms that occurred during 1990-93. The hourly total precipitation data were then disaggregated at 5-minute intervals. A comparison of the depth-duration data collected during 1990-93 at the USGS stations with the data collected at other stations indicated that the 1990-93 data were not representative of historical storms. Therefore, depth-duration ratios developed using these data was considered preliminary for use in disaggregating the historical hourly data for Antelope valley.

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12 *Title:* **Urban Hydrology in the Desert, Antelope Valley, California**

Hydraulics/Hydrology of Arid Lands (H2AL)

Author: Blodgett, J.C., Nasseri, I., Elliott, A.L.

Publication Date: 1990

Publication Info: ASCE Conf. Proceedings

Summary: As part of a cooperative study by the USGS and Los Angeles County Department of Public Works, the study of urban hydrology in Antelope Valley, about 50 miles north of Los Angeles, began in October 1988. This article discusses effect of urbanization on runoff analyses in support of land development and typical channel alterations in the vicinity of water conveyance systems (e.g., gutters, siphons), and highway structures (e.g., culverts, bridges). The then flood-control system in the Antelope Valley was inadequate, resulting in extensive overbank flooding in March 1983. Much of the western and southern part of Antelope Valley, particularly along foothills and on the alluvial fans, were undergoing urbanization at the time the cooperative study was undertaken. The inevitable consequences of urbanization in the Antelope Valley included significant changes in runoff magnitude, timing, and duration compared with historical events. Hydrologic data, which are limited in Antelope Valley, were necessary to develop and verify methods to determine basin rainfall-runoff characteristics. The streamflow and rainfall gaging stations established in the valley were at sites selected to provide areal diversity in basin size, slope, exposure, soil types, and urbanization. Streamflow data from these stations were used to calculate peak discharge, daily mean flow discharge, and flood hydrograph volumes in the first two phases of the study, and also for rainfall-runoff modeling in the final phase. Soil infiltration data is typically sparse in the arid southwest. Infiltration measurements, needed as input for rainfall-runoff models, were conducted. A typical approach in frequency relations development has been to fit a log-Pearson distribution to available observed precipitation and streamflow data, and compare the results with research-based relations developed by others. This paper discusses the results from frequency relation generation for annual maximum 24-hour precipitation using the log-Pearson analysis, and plots a comparison chart with results obtained from other relations. The same procedure was established for streamflow frequency analysis. Notable differences in recurrence intervals obtained between relations utilized indicated the need for additional data collection in the valley.

13 *Title:* **Sediment Yield from Agricultural Watersheds**
Author: Bogardi, I., Bardossy, A., Fogel, M., Duckstein, L.
Publication Date: January 1986
Publication Info: Journal of Hydraulic Engineering, Vol. 112, No. 1, pp. 64-70

Summary: The purpose of this paper is to apply various methods for calculating sediment yield from agricultural watersheds and to check the accuracy of the calculations by comparing the results with measured data. The methods used to calculate sediment yield include regional regression, USLE with delivery ratio, MUSLE, and simulation models (CREAMS).

14 *Title:* **NOAA Atlas 14, Precipitation-Frequency Atlas of the United States**
Volume 1: Semiarid Southwest (Arizona, Southeast, California, Nevada, New Mexico, Utah)
Author: Bonnin, G.M., Todd, D., Lin, B., Parzybok, T., Yekta, M., and Riley, D.
Publication Date: 2004
Publication Info: NOAA National Weather Service

Summary: NOAA Atlas 14 volume 1 contains precipitation frequency estimates for Arizona, Nevada, New Mexico, Utah, and southeastern California (Imperial, Indio, eastern Kern, eastern Los Angeles, Riverside, San Bernardino, and eastern San Diego counties). The atlas is intended as the official documentation of precipitation frequency estimates and associated information for the aforementioned states and counties. It includes discussion of development methodology, and intermediate results. The Precipitation Frequency Data Server (PFDS) was developed and published in tandem with this Atlas to allow delivery of the results and supporting information in multiple forms via the internet. Appendix A.1 provides temporal distributions of heavy precipitation for use with precipitation frequency estimates from NOAA Atlas 14 Volume 1 for 6-, 12-, 24-, and 96-hour durations covering the semi-arid southwestern United States. The temporal distributions are expressed in probabilistic terms as cumulative percentages of precipitation and duration at various percentiles. The starting time of precipitation accumulation was defined in the same fashion as it was for precipitation frequency estimates for consistency. The data were also subdivided into quartiles based on where in the distribution the most precipitation occurred in order to provide more specific information on the varying distributions that were observed. Digital date to generate all temporal distribution curves are available at: http://hdsc.nws.noaa.gov/hdsc/pfds_temporal.html

15 *Title:* **Flood Frequency Estimates in Southeastern Arizona**
Author: Boughton, W.C., Renard, K.G., Stone, J.J.
Publication Date: November 1987
Publication Info: Journal of Irrigation and Drainage Engineering, Vol. 113, No. 4, pp. 469-478

Summary: The effect of the October 1983 floods in southeastern Arizona, on a previously established generalized envelope for floods expected once in 100 years (Q100), is studied. The design envelope is found to produce more conservative estimates of Q100 than individual data sets find. The design envelope for Q100 is revised to correct for some longer periods of record now available, and to be consistent with floods on a wider range of drainage area than previously considered. Additional design envelopes for Q2 and Q10 are prepared, and the three envelopes are used to provide conservative estimates of flood frequencies on ungaged watersheds in southeastern Arizona with drainage areas between 0.01 sq. km. and 10,000 sq. km.

16 *Title:* **Urban Drainage Design Manual**
Hydraulic Engineering Design Circular 22, Second Edition
Author: Brown, S. A., Stein, S. M., Warner, J. C.
Publication Date: July 2001
Publication Info: Federal Highway Administration FHWA-NHI-01-021

Summary: This circular provides a comprehensive and practical guide for the design of storm drainage systems associated with transportation facilities. Design guidance is provided for the design of storm drainage systems which collect, convey, and discharge stormwater flowing within and along right-of-way. Methods and procedures are given for the hydraulic design of storm drainage systems. Design methods are presented for evaluating rainfall and runoff magnitudes, pavement drainage, gutter flow, inlet design, median and roadside ditch flow, structure design, and storm drain piping. Procedures for the design of detention facilities are also presented, along with an overview of storm water pumping stations and urban water quality practices.

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17 *Title:* **Adoption of Flood Flow Frequency Estimates at Ungaged Locations**
Author: Burnham, M. W.
Publication Date: February 1980
Publication Info: U.S. Army Corps of Engineers, Hydrologic Engineering Center TD-11

Summary: This document presents the concept of adopting flood flow frequency relationships at ungaged locations. The method compares the flood flow frequency results from various procedures and adopts a frequency curve. The use of the adopted frequency curve concept provides insight to the variability and reliability of the results which generally leads to better estimate of flood flow frequencies. The emphasis is placed on the need for professionals performing the analyses to understand the available procedures, study considerations that affect the analyses and utilization of field reconnaissance information, all of which influence the evaluation process and subsequent reliability of results.

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18 *Title:* **California Beach Restoration Study**
Author: California Dept. of Boating and Waterways and State Coastal Conservancy
Publication Date: January 2002
Publication Info:

Summary: In this study, all water discharge and sediment data published by the USGS through the 1999 water year have been compiled for the most seaward gaging stations for California's 34 gaged coastal streams to characterize the long-term fluvial delivery of beach material to the coast. Suspended sediment transport was estimated using a standard rating curve technique. The daily estimated and measured suspended sediment fluxes were summed by water year.

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19 *Title:* **Emergency Assessment of Debris-Flow Hazards from Basins Burned by the Grand Prix and Old Fires of 2003, Southern California**
Author: Cannon, Susan H., Gartner, Joseph E., Rupert, Michael. John A.; Djokic, Dean, and Sreedhar, Sr
Publication Date: 2003
Publication Info: USGS Open-File Report 03-475

Summary: The USGS open-file report summarizes the debris-flow hazard probability maps. These maps present preliminary assessments of the probability of debris-flow activity and estimates of peak discharges that can potentially be generated by debris flows issuing from basins burned by the

Old and Grand Prix Fires of October 2003 in Southern California in response to the 25-, 10-, and 2-year recurrence, 1-hour storm duration. The probability maps were derived from logistic multiple regression model that describes the percent chance of debris-flow production from an individual basin as function of burned extent, soil properties, basin gradients, and storm rainfall. The peak discharge maps are based on application of a multiple-regression model that can be used to estimate debris-flow peak discharge at a basin outlet as a function of basin gradient, burn extent, and storm rainfall. The maps are intended to identify those basins that are most prone to the largest debris-flow events and provide critical information for the preliminary design of mitigation measures and for the planning of evacuation timing and routes.

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20 *Title:* **Assessment of Potential Debris-Flow Peak Discharges From Basins Burned by the 2002 Coal Seam Fire, Colorado**

Author: Cannon, Susan H., Michael, John, A, , and Gartner, Joseph E.

Publication Date: 2003

Publication Info: USGS Open-File Report OF-03-333

Summary: The primary goal of the case study presented in this USGS open-file report was to estimate the potential magnitude of possible debris-flow events, for given storm conditions, from the basins burned by the Coal Seam fire of June through July 2002 in Colorado. A range of peak discharges that can be generated by debris flow from individual burned basins is calculated using a multiple-regression model. The data, measured from post-wildfire debris flows, was used to define the range of peak discharges that can potentially be generated from the basins. The data uses in the regression model development consists of measurements from 53 recently burned basins located throughout the western United States, and is a compilation of information both from the published literature and USGS monitoring efforts. The regression model consists of a physical representation of peak discharge relative to average rainfall intensity as a function of basin gradient and burned extent. The method used to accomplish the task has not been thoroughly tested and reviewed since this was the first time the regression model was applied to recently burned basins. However, since the method is based on analysis of data from post-wildfire debris flows rather than estimates of flood runoff with assumed sediment-bulking factors, the use of the method leads to some advantages.

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21 *Title:* **Flood Potential of Topopah Wash and Tributaries, Eastern Part of Jackass Flats, Nevada Test Site, Southern Nevada**

Author: Christensen, R.C., and Spahr, N.E.

Publication Date: 1980

Publication Info: USGS Open-File Report 80-963

Summary: This report evaluates the flood potential of streams in a small area in southern Nevada. Regression equations are included for the 10-, 25-, 50-, and 100-year floods that are applicable statewide.

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22 *Title:* **Hydrologic Criteria and Drainage Design Manual**

Author: Clark County Regional Flood Control District

Publication Date: August 1999

Publication Info:

Summary: The best method for determining stormwater runoff is to measure the runoff from a flood with a known intensity and recurrence interval. Since this approach is seldom practical, various analytical methods have been developed which predict the stormwater runoff from preselected hydrologic conditions. These methods are referred to as deterministic models. Other methods evaluate measured past trends to predict future trends, which are referred to as probabilistic methods (dependent on chance such as a statistical analysis). The general lack of sufficient rainfall/runoff data in the Clark County area presently precludes the use of probabilistic models for normal stormwater runoff calculations. If the drainage area is less than or equal to 150 acres, the recommended methods are the Rational Method, the NRCS TR-55 method, or HEC-1 (using SCS unit hydrograph or kinematic wave). If the drainage area is greater than 150 acres, using HEC-1 (using SCS unit hydrograph or kinematic wave) is suggested.

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23 *Title:* **Coconino County Drainage Design Criteria**

Author: Coconino County Public Works Department

Publication Date: January 2001

Publication Info:

Summary: Coconino County's hydrology procedures consist of: 1) the rational equation method, 2) NRCS's TR-55 method, and 3) the HEC-1 method. This report gives a short summary of these three methods.

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24 *Title:* **Relationship of Sediment Discharge to Streamflow**

Author: Colby, B.R.

Publication Date: April 1956

Publication Info: USGS Open-File Report 56-27

Summary: The relationship between the rate of sediment discharge and the rate of water discharge at a cross section of a stream is frequently expressed by an average curve. This curve is the sediment rating curve, which has been widely used in the computation of average sediment discharge from water discharge for periods when sediment samples were not collected. This report discusses primarily the applications of sediment rating curves for periods during which at least occasional sediment samples were collected.

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25 *Title:* **Discharge of Sands and Mean-Velocity Relationships in Sand-Bed Streams**

Sediment Transport in Alluvial Channels

Author: Colby, B.R.

Publication Date: 1964

Publication Info: USGS Professional Paper 462-A

Summary: Estimation of sediment yield was accomplished by a combination of graphical and analytical multiple regression methods. Graphical correlation was necessary to determine which variable to consider and the required transformation of the data, and to note unusual elements of the relationship. The analysis was performed using data for seven stream locations in the Atlantic coast area.

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26 *Title:* **A Comparison of Methods Used in Flood Frequency Studies for Coastal Basins in California**

Author: Cruff, R. W., Rantz, S. E.

Publication Date: 1965

Publication Info: USGS Water Supply Paper 1580-E

Summary: This study compares the results of regional flood-frequency studies made by several methods and appraises the relative reliability of these methods. The areas selected for study were the sub-humid San Diego area in southwestern California and the humid coastal area in northwestern California. The following six methods of analysis were applied to each region: Index-flood method, multiple correlation, logarithmic normal distribution, extreme-value probability distribution (Gumbel method), Pearson type III distribution, and gamma distribution. The last four methods named involved not only the computation of the statistics appropriate to the distributions, but also the relating of these statistics to basin and climatologic characteristics.

27 *Title:* **Flood Frequency Analyses, Manual of Hydrology: Part 3. Flood Flow Techniques**
Methods and practices of the Geological Survey
Author: Dalrymple, Tate
Publication Date: 1960
Publication Info: USGS Water Supply Paper 1543-A

Summary: This report describes the method used by the U.S. Geological Survey to determine the magnitude and frequency of momentary peak discharges at any place on a stream, whether a gaging-station record is available or not. The method is applicable to a region of any size, as a river basin of a State, so long as the region is hydrologically homogenous. The analysis provides two curves. The first expresses the flood discharge-time relation, showing variation of peak discharge, expressed as a ratio to the mean annual flood, with recurrence interval. The second relates the mean annual flood to the size of drainage area alone, or to the size and other significant basin characteristics.

28 *Title:* **Graphical Verification of Flood Frequency Analysis**
Hydraulics/Hydrology of Arid Lands (H2AL)
Author: de Roulhac, D.G.
Publication Date: 1990
Publication Info: ASCE Conf. Proceedings

Summary: A graphical method is described to help choose the proper statistical distribution to fit hydrologic data for flood frequency analysis. The paper encourages deviation from the use of improper application of statistical models simply because of its widespread use. Graphical techniques, when used in conjunction with numerical techniques, provide the option to select the most appropriate statistical distribution for a particular watershed. To assist in the graphical verification, the paper refers to the utility of classical statistical plotting methods namely, normal or log-normal “paper” on which a plotting position is applied, and the extreme value “paper” that is often used with annual precipitation maxima. The choice of distribution depends on the type of plotting “paper” utilized in the analysis. This gives a feel for what information the data conveys. Reference is also made to the Bulletin 17B which discourages the use of Gumbel’s extreme value distribution in favor of Log Pearson III distribution, and a special case where the skew is zero, the log normal distribution.

29 *Title:* **Sediment Yield-Runoff-Drainage Area Relationships in the United States**
Author: Dendy, F.E., and Bolton, G.C.
Publication Date: Nov/Dec 1976
Publication Info: Journal of Soil and Water Conservation, Vol. , No. , pp. 264-266

Summary: Watershed sediment yields, as determined from sediment deposits in about 800 reservoirs, were related to drainage area size and mean annual runoff. The average sediment yields per unit of net drainage area were inversely proportional to the 0.16 power of the drainage area. Average sediment yields increased sharply to about 1,860 tons per square mile of drainage area as runoff increased from 0 to about 2 inches and then decreased as runoff increased from 2 to about 50 inches.

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30 *Title:* **Hydrologic Analysis of Ungaged Watersheds Using HEC-1**

Author: DeVries, J.J.

Publication Date: April 1982

Publication Info: U.S. Army Corps of Engineers, Hydrologic Engineering Center TD-15

Summary: This report is a significant contribution from HEC in regards to hydrologic frequency analyses for ungaged watersheds. Much of the desert and rangelands of the southwestern U.S. remain ungaged to date, thus hypothetical rainfall data are often the only rainfall data available. The report provides detail analyses of such watersheds using HEC-1. Effects of the extent of data availability on choice of approach, and regionalization of hydrologic parameters are also discussed. Hydrologic tools used to model the ungaged watersheds discussed include the Clark Unit Hydrograph, Holtan's loss rate method, and the Kinematic wave routing. Three case studies represent unique basin conditions in terms of streamflow and discharge-frequency data availability. Highway development projects on watersheds with limited data will benefit from the detailed discussion in this report.

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31 *Title:* **Flood Frequency Estimates on Alluvial Fans**

Author: Dowdy, D.R.

Publication Date: November 1979

Publication Info: ASCE Journal of the Hydraulics Division, Vol. 105, No. HY11, pp. 1407-1413

Summary: One of the major problems in the determination of shallow flooding probabilities on alluvial fans is that the probability with which a flood occurs at the apex of a fan does not alone determine the probability of flooding or of resulting flood depth at any point on the fan below the apex. As an alluvial fan widens, the probability of flooding of a given magnitude at a given point should decrease. A method is presented in this paper to assess that change in probability and to develop a strategy for computing such a probability at any point on an alluvial fan.

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32 *Title:* **Chapter C2: Field Methods for Measurement of Fluvial Sediment**

Book 3, Applications of Hydraulics

Author: Edwards, T.K., Glysson, G.D.

Publication Date: 1999

Publication Info: USGS Techniques of Water-Resources Investigations B3-C2

Summary: This chapter describes equipment and procedures for collection and measurement of fluvial sediment.

In addition to an introduction, the chapter has two major sections. The "Sediment-Sampling equipment" section encompasses discussions of characteristics and limitations of various models of depth- and point integrating samplers, single-stage samplers, bed-material samplers, bedload samplers, automatic pumping samplers, and support equipment. The "Sediment-Sampling Techniques" section includes discussions of representative sampling criteria, characteristics of sampling sites, equipment selection relative to the sampling conditions and needs, depth and point-integration techniques, surface and dip sampling, determination transit rates, sampling

programs and related data, cold-weather sampling, bed-material and bedload sampling, measuring total sediment
discharge, and measuring reservoir sedimentation rates.

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33 *Title:* **Urban Flood Frequency Characteristics**

Author: Espey, W.H. Jr., Winslow, D.E.

Publication Date: February 1974

Publication Info: ASCE Journal of the Hydraulics Division, Vol. 100, No. HY2, pp. 279-293

Summary: Some of the early urban hydrology work that dealt with the effects of urbanization on flood potential of small urban watersheds concluded that flood peaks can increase by 1.5 to 5 times after urbanization. However, this dramatic increase in peak discharge becomes less significant for floods of increasing magnitude. In the past, urban hydrology projects have been limited by the unavailability of urban hydrologic data. This paper presents a preliminary flood frequency analysis (Log-Pearson Type III) of 60 relatively small watersheds located throughout the US.

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34 *Title:* **Estimation of Magnitude and Frequency of Floods in Pima County, Arizona, with Comparisons of Alternative Methods**

Author: Eychaner, J.H.

Publication Date: August 1984

Publication Info: USGS WRI Report 84-4142

Summary: In Pima County, Arizona, a semiarid region of large relief, new regression equations estimate 5- to 100-year flood discharges are developed. Less accurate equations are also developed for the 2- and 500-year discharges. Predictor variables used are: drainage area (0.013 to 4,471 square miles), channel slope (0.3 to 13 percent), and shape factor. Estimates for gaged sites are a variance-weighted average of estimates from regressions and from gage data. Estimates for the Tucson urban area are based on equations developed in a nationwide study. Two methods for estimating flood discharges from gage records, two sets of new regressions, and two previously published regional methods are compared. Distribution-free tests against maximum observed floods show differences in accuracy between the methods, and comparisons with base methods show differences in variability. The tests and comparisons indicate that the new equations are more accurate and less variable than methods previously published.

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35 *Title:* **Regional Flood Frequency Analysis in Arid and Semi-Arid Areas**

Author: Farquharson, F.A.K., Meigh, J.R., and Sutcliffe, J.V.

Publication Date: 1992

Publication Info: Journal of Hydrology, Vol. 138, No. , pp. 487-501

Summary: Regional flood frequency curves in a number of semi-arid and arid areas have been assembled to illustrate their extreme slope and skewness and the mutual similarity of these curves. Annual maxima from 162 stations with annual basin rainfall below 600 mm were assembled from NW Africa, Iran, Jordan, Saudi Arabia, Botswana, and South Africa and compared with records from Australia, southwest USA, and Russia.

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36 *Title:* **Managing Floodplain Development in Approximate Zone A Areas**

A Guide for Obtaining and Developing Base (100-year) Flood Elevations

Author: Federal Emergency Management Agency
Publication Date: April 1995
Publication Info: 265

Summary: There are a number of methodologies that may be used to develop flood discharges. The methods discussed in this report were selected because they are fairly simple to use, require information that is easily obtainable, and provide reasonable discharge estimates for streams where more detailed hydrologic analyses have not been performed. These methods include discharge-drainage area relations, regression equations, the TR-55 graphical method, and the Rational Method. Limitations are given for each of these methods.

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37 *Title:* **Predicting sediment yield in western United States**
Author: Flaxman, E.M.
Publication Date: December 1972
Publication Info: ASCE Journal of Hydraulics Division, Vol. 98, No. HY12, pp. 2073-2085

Summary: The paper summarizes a multiple regression based sediment yield study conducted over 11 western states. Measurements of sediment deposition in small reservoirs and stock ponds to determine sediment yield were used as dependent variable. Watershed characteristics thought to affect sediment yield and subject to quantitative determination were measured, and used as independent variable in a multiple regression analysis. The four selected independent variables are the climate, the topography, and two variables for soil characteristics. The application of the resulting equation in determining site hazard is also described.

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38 *Title:* **Runoff Estimates for Small Rural Watersheds and Development of a Sound Design Method**
Volume I: Research Report
Author: Fletcher, J.E., Huber, A.L., Haws, F.W., and Clyde, C.G.
Publication Date: October 1977
Publication Info: Federal Highway Administration FHWA-RD-77-158

Summary: Frequency analyses of more than 1000 small watersheds in the United States were used to develop the estimation method for the design of peak flow for ungaged watersheds. This method, called the FHWA method, is conceptually similar to Potter's method. The FHWA method relates the runoff peak to easily determined hydrophysiographic parameters and is intended for use on watersheds smaller than 50 square miles. The concept of risk is incorporated into the recommended design procedure. The return period of the design flood peak can be modified according to the risk the designer is willing to take.

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39 *Title:* **Runoff Estimates for Small Rural Watersheds and Development of a Sound Design Method**
Volume II: Recommendations for Preparing Design Manuals and Appendices B, C, E, F, G, and H
Author: Fletcher, J.E., Huber, A.L., Haws, F.W., and Clyde, C.G.
Publication Date: October 1977
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40 *Title:* **Drainage Design Manual for Maricopa County, Arizona**
Hydraulics
Author: Flood Control District of Maricopa County
Publication Date: October 2002
Publication Info:

Summary: The selection of the procedure used to determine the design flood hydrology is dependent upon the intended application. For small urban watersheds (defined as less than 160 acres and having fairly uniform land use), the use of the Rational Method is acceptable. Use of this method will only produce peak discharges and it should not be used if a complete runoff hydrograph is needed, such as for the routing of flow through a detention facility. For larger, more complex watersheds or drainage networks, a rainfall-runoff model should be developed. The Hydrology Manual provides guidance in the development of such a model and the estimation of the necessary input parameters to the model. All the hydrology required for the design of stormwater storage facilities that are normally encountered can be performed by using the HEC-1 program.

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41 *Title:* **Drainage Design Manual for Maricopa County, Arizona**
Hydraulics
Author: Flood Control District of Maricopa County
Publication Date: September 2003
Publication Info: Chapter 10

Summary: Chapter 10 of the Drainage Design Manual of Maricopa County (Hydraulics) covers sedimentation issues applicable in the desert southwest. Among topics covered are: 1) nature of erosion and sedimentation, 2) sedimentation issues such as sand and gravel mining, watercourse stabilization, stormwater storage, and water quality issues, 3) channel processes, 4) sediment properties, 5) equilibrium concept, 6) sediment discharge rating curve, 7) water sediment yield determination methods, 8) sediment transport mechanism, 9) bank erosion and lateral migration, 10) estimation of general, contraction, and local scour including limits to scour from armoring of bed material. In a nutshell the chapter covers technical issues related to sediment transport in relation to aggradation and degradation.

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42 *Title:* **Debris Method - Los Angeles District Method for Prediction of Debris Yield**
Author: Gatwood, Elden, Pedersen, John, and Casey, Kerry
Publication Date: February 1992
Publication Info: U.S. Army Corps of Engineers, Los Angeles District

Summary: The objective of this study was to develop a method to estimate unit debris yield values for n-year flood events for the design and analysis of debris-catching structures in coastal Southern California watersheds, considering the coincident frequency of wildlife and flood magnitude. These structures are normally sized to intercept debris from a single large flood event. Flood history in Southern California clearly demonstrates the debris yield hazard as being associated with singular storm events. The necessity for a single-event approach to debris yield versus a long-term approach is explained in part by examination of daily suspended sediment discharge measurements taken by the USGS in selected coastal Southern California watersheds. Multiple linear regression analysis was selected as the method by which unit debris yield was determined. Regression analysis indicated that the unit debris is most highly correlated with the unit peak runoff rate from a watershed (or the maximum 1-hour precipitation depth), the relief of the drainage basin, the contributing basin area, the fire history, and the geomorphic characteristics of the watershed. The report states several limitations on the use of the method in terms of geographic location, drainage area constraints, topographic constraints, and frequency and regression model input constraints.

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43 *Title:* **Modern Sediment Yield Compared to Geologic Rates of Sediment Production in a Semi-Arid Basin, New Mexico**

Assessing the Human Impact

Author: Gellis, A.C., Pavich, M.J., Bierman, P.R., Clapp, E.M., Ellevein, A., and Aby, S.

Publication Date: 2004

Publication Info: Earth Surface Processes and Landforms, Vol. 29, No. , pp. 1359-1372

Summary: In the semi-arid Arroyo Chavez basin of New Mexico, short term sediment yield measured with sediment traps was shown to contrast with long term sediment production. The geologic rate of sediment production is similar to the modern sediment production.

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44 *Title:* **Quantifying Uncertainty in Estimates of Regulated Flood Frequency Curves**

Bridging the Gap

Author: Goldman, D.M.

Publication Date: 2001

Publication Info: ASCE Conf. Proceedings

Summary: The Corps of Engineers uses the uncertainty in estimated flood frequency curves to both evaluate the benefits of flood damage reduction measures and for delineating the regulatory flood plain. Quantifying this uncertainty in estimated regulated flood frequency curves is complicated by: 1) the statistical sampling error involved in estimating the reservoir system inflow frequency curves; 2) estimating the storage in the reservoir system prior to an inflow event; and 3) operational contingencies. The statistical sampling error in the reservoir inflow frequency curve can be quantified by standard statistical methods. The contribution to uncertainty due to reservoir operations is not easily estimated, being a function of numerous factors including flood forecast uncertainty and the deviations from set operation guidelines during emergency operations. Quantifying the contribution to uncertainty from estimating the initial storage depends on the approach taken to developing inflow frequency curve estimates and the operating characteristics of the reservoir system. A case study will be presented describing methods for obtaining best estimates of the regulated flood distribution and the uncertainty in this estimate.

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45 *Title:* **The LP3 Distribution and Its Use for Flood Frequency Analysis**

Impacts of Global Climate Change

Author: Griffis, V. W., Stedinger, J. R.

Publication Date: May 2005

Publication Info: EWRI

Summary: Knowledge of magnitude and frequency of floods is needed for the design of highway drainage structures. The Log Pearson 3 (LP3) distribution has been used for several decades to model annual flood series. Whether an LP3 model of annual flood series is reasonable depends on two parameters: the regional skew and standard deviation range. This paper explores the characteristics of the LP3 distribution in log and real space, and their relationship. Among a wide range of alternative parameter estimation methods for the LP3 distribution explored in the hydrologic literature, the method of moments (MOM), maximum likelihood estimator (MLE), and mixed moments (MXM) are notable. While the method of mixed moments does very well in comparison to MOM and MLE in the absence of regional information, Monte Carlo analysis implemented in this study demonstrates that the MOM estimator with regional skew information as recommended by Bulletin 17B [IACWD, 1982] is more attractive. The more precise the regional skew estimators the more precise are the flood quantile estimators. An extension to the studies found in hydrologic literature on LP3 distribution parameter estimation, this paper discussed the employment of regional skew information to improve the accuracy of the skew coefficient. The Monte Carlo analysis evaluates the efficiency of the Bulletin 17B MOM estimator with regional skew information relative to MLEs and MXM estimator. The parameter estimation methods are compared using the mean square error (MSE) of the T-year event namely, the 100-year event [Q0.99]. Data for the experiment is generated from LP3 populations, and log space regional skews between -1.0 and +1.0. The major conclusion is that as long as the log space skew is less than or equal to one, the LP3 distribution remains very log-normal like and provides a mathematically sound model for annual maximum series, such as annual floods at most locations in the United States where zero annual maximum are rare.

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46 *Title:* **Initiation and Frequency of Debris Flows in Grand Canyon, AZ**

Author: Griffiths, P.G., Webb, R.H., Melis, T.S.

Publication Date: 1996

Publication Info: USGS Open-File Report 96-491

Summary: This study provides an analysis of initiation mechanisms and frequency of historic debris flows in Grand Canyon National Park and vicinity, Arizona. The data presented here will be used as the basis for development of sediment-yield estimates from ungaged tributaries of the Colorado River, a critical element of long-term management of resources downstream from Glen Canyon Dam (U.S. Department of Interior, 1995). This report incorporates existing information on debris-flow frequency in Grand Canyon, and includes 600 tributaries of the Colorado River between Lees Ferry and Surprise Canyon, Arizona (fiver miles 0 to 248), excluding the Paria and Little Colorado Rivers and Kanab and Havasu Creeks. Repeat photography from the 1889-1890 Stanton expedition (Webb, 1996) provides uniform data for estimation of the binomial frequency of debris flows in 164 tributaries in Grand Canyon. Logistic regression is used to develop a statistical model based on measured morphometric, lithologic, and climatic variables from these 164 tributaries for estimation of the probability of debris-flow occurrence in all 600 geomorphically significant tributaries.

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47 *Title:* **Discharge Frequency Analysis for Alluvial Fans/Arid Regions -- Statistical Approach**

Land Use and Flood Damages in Arid and Semi-Arid Areas

Author: Hagen, V.K.

Publication Date: December 1992

Publication Info: Proceedings of the Conference on Arid West Floodplain Management Issues

Summary: This is a companion paper to "Discharge Frequency Analysis for Alluvial Fans/Arid Regions -- Rainfall-Runoff Approach" by M. Khine. This paper concentrates on flood frequency analyses.

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48 *Title:* **Precipitation History of the Mojave Desert Region, 1983-2001**
Author: Hereford, R., Webb, R.H., and Longpre, C.I.
Publication Date: 2004
Publication Info: USGS Fact Sheet 117-03
Summary: The precipitation history of the Mojave Desert region from 1893 to 2001 is drawn based on annual and seasonal precipitation records, relation between precipitation trend and global climate indices such as Sea Surface Temperature (SST), short-term variation due to El Nino and La Nina, and long-term variation related to the Pacific Decadal Oscillation (PDO). The study concludes that precipitation in the Mojave Desert region varied substantially during the past century. Recent trend in Mojave Desert precipitation and the PDO suggest that the climate of the region may become drier for the next 2 to 3 decades in a pattern that could resemble the mid-century dry conditions. Water resources of the region were heavily affected during the early part of the 1942-1977 dry conditions, and the precipitation of the region has increased greatly since the mid- 1950's, substantially increasing the demand for water in an arid region and creating the possibility of severe consequences if such droughts were repeated. The paper stresses for a better understanding of the precipitation pattern of the region given the uncertainties involved in the future trend prediction process.

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49 *Title:* **Synthetic Rain Flood Hydrology for the Sacramento and San Joaquin River Basins**
Author: Hickey, J.T., Collins, R.F., High, J.M., Richardson, K.A., White, L.L., and Pugner, P.E.
Publication Date: May 2002
Publication Info: Journal of Hydrologic Engineering, Vol. 7, No. 3, pp. 195-208
Summary: In response to various destructive floods, the USACE and the State of California are investigating flood damage reduction and ecosystem restoration opportunities in the Sacramento and San Joaquin River Basins in California. This paper provides a short background on the study and details the methodology used to develop the baseline technical hydrology needed to support ongoing system analyses and modeling efforts. Discussion emphasizes conceptual relations between rain flood hydrology and floodplain delineation and a method for developing synthetic flood hydrographs.

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50 *Title:* **Sediment Loads in the Ventura River Basin, Ventura County, California, 1969-81**
Author: Hill, B.R., McConaughy, C.E.
Publication Date: 1988
Publication Info: USGS Water Resources Investigations 88-4149
Summary: For this report, previously collected data were used to define relations between coarse-suspended-sediment and bedload transport and streamflow at the Ventura River near Ventura and at San Antonio Creek at Casitas Springs. These relations were then applied to existing records of average daily streamflow to estimate coarse-suspended-sediment load and bedload for the periods of sediment-data collection.

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51 *Title:* **Flood Hydrology Near Flagstaff, Arizona**
Author: Hill, G. W., Hales, T. A., Aldridge, B. N.
Publication Date: June 1988
Publication Info: USGS WRI Report 87-4210

Summary: Peak discharges measured at 11 crest-stage gages near Flagstaff were used to determine discharges that have recurrence intervals of 2, 5, 10, and 25 years. The discharges were related to drainage area and urban development in order to provide equations for design of hydraulic structures in the Flagstaff area. Peak discharges in various parts of the city differ considerably. The differences are due to combinations of several drainage-basin characteristics. Coefficients for the rational formula were computed for drainages of less than 10 square miles. Coefficients for undeveloped rural basins are less than 0.1; coefficients for urban development range from 0.05 to 0.39. This range in values indicates that, with some limitations, coefficients found in general engineering handbooks for urban types of land use are applicable for design in Flagstaff.

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52 *Title:* **Regional Flood Frequency Relations for Streams with Many Years of No Flow**
Hydraulics/Hydrology of Arid Lands (H2AL)

Author: Hjalmarson, H.W., Thomas, B.E.

Publication Date: 1990

Publication Info: ASCE Conf. Proceedings

Summary: A new method of estimating regional flood-frequency information for arid regions is proposed. The method uses all available annual peak-discharge data including years of no flow at gaging stations in the area of interest. The proposed method, called the hybrid method, is based on the station-year method of frequency analysis suggested for use on flood by Fuller (1914). The station-year method assumes that independent records from a homogeneous region can be combined to form the long composite record if the peaks of the individual records can be reduced to a common base. The hybrid method incorporates the station-year approach with a method of standardization to produce regional flood-frequency relations based on basin and climatic parameters. The performance of the hybrid method was evaluated by comparison with regional relations determined from a standard regionalization for 12 gaging stations in the Uinta Mountains in northern Utah. A six-step iterative technique was used to determine a two-parameter regional flood-frequency relation. The two independent variables are drainage area and mean basin elevation.

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53 *Title:* **New Look at Regional Flood Frequency Relations for Arid Lands**

Author: Hjalmarson, H.W., Thomas, B.E.

Publication Date: June 1992

Publication Info: Journal of Hydraulic Engineering, Vol. 118, No. 6, pp. 868-886

Summary: In the southwestern US, flood frequency relations for streams that drain small arid basins are difficult to estimate, largely because of the extreme temporal and spatial variability of floods, many years of no flow, and short periods of systematic records of annual peaks. A new method is proposed that combines records for several streamflow gaging stations, as in the station-year approach, and produces regional flood frequency relations using an iterative regression technique. The technique eliminates the need to extrapolate the flood frequency relation to the flood probability of interest. The method was applied to a group of records from 42 gaging stations in Nevada with many years of no flow and with many poorly defined flood frequency relations.

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54 *Title:* **Rainfall/Runoff Modelling Procedures for the Arid Southwest**
Land Use and Flood Damages in Arid and Semi-Arid Areas

Author: Hromadka, T. V., II

Publication Date: December 1992

Publication Info: Proceedings of the Conference on Arid West Floodplain Management Issues

Summary: This paper is a comparison of the hydrology manuals for Clark County NV, Maricopa County AZ, San Bernardino County CA, San Diego County CA, Riverside County CA, and Kern County CA.

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55 *Title:* **Hydrologic Modeling for the Arid Southwest United States**

Author: Hromadka, T. V., II

Publication Date: 1996

Publication Info: Mission Viejo, CA: Lighthouse Publications

Summary: Hydrology manuals from San Bernardino County (1986), Riverside County (1978), San Diego County (1985), Clark County, NV (1990), and Maricopa County, AZ (1990) were compared with regard to runoff modeling techniques, design storm input, rainfall mass vs. critical duration, effective rainfall determination (i.e., loss rates), confidence intervals, and stream gage data. Although newer editions of some of these manuals are available, this book provides a detailed analysis of the various hydrologic methods and parameters that were used (or are still being used) by these arid-region counties.

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56 *Title:* **Regional Flood Frequency Analysis Accounting for Sporadic Thunderstorms in North Central Oregon**

Interdisciplinary Solutions for Watershed Sustainability

Author: Hu, H., Bennett, T., Thomas Jr., W., and Weber, J.

Publication Date: April 2006

Publication Info: Proceedings of the Joint 8th Federal Interagency Sedimentation Conference and 3rd Federal Inte

Summary: Regional flood-frequency relations are developed for streams in the Willow Creek basin and other small streams in north central Oregon. It is difficult to derive such relations in the region, largely because of the extreme temporal and spatial variability of thunderstorm-driven floods. Due to limitations of a conventional flood frequency regression method, the majority of flood events from large thunderstorms are unrepresented in the systematic flow record used to develop conventional regional regression equations. The study applied a hybrid regression method to develop a set of regional regression equations that incorporate isolated thunderstorm summer peaks. A distinguishing characteristic of the hybrid method is that it combines all peak flow records within a hydrologically similar region into one data set. This includes all peaks (zero or non-zero flows) at gaging stations with long-term or short-term records and a number of historic thunderstorm peak discharges at ungaged sites. The paper describes the basic steps for performing a hybrid regression analysis including a test case for evaluating the applicability and accuracy of the hybrid method in the study region. The hybrid method is then applied to Willow Creek and its tributaries in Morrow County, Oregon to develop a set of regression equations for use in FEMA Flood Insurance Study.

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57 *Title:* **Magnitude and Frequency of the Floods of January 1997 in Northern and Central California**

Preliminary Determinations

Author: Hunrichs, R.A., Pratt, D.A., Meyer, R.W.
Publication Date: 1998
Publication Info: USGS Open-File Report 98-626

Summary: Preliminary determinations of the magnitude and frequency of peak flows resulting from the storms of December 1996 and January 1997 were made at 292 stream flow gaging stations located in 45 counties in northern and central California. For this report, annual peak flows were used to define frequency curves using one of two methods: 1) the Water Resources Council (WRC) method, which is a statistically-based analysis of annual peak flows recommended by the U.S. Water Resources Council in "Guidelines for Determining Flood Flow Frequency, Bulletin 17B of the Hydrology Subcommittee", and 2) the graphical method, in which a frequency curve is fit to annual peaks plotted on a logarithmic probability graph.

58 *Title:* **Guidelines for Determining Flood Flow Frequency**
Author: Interagency Advisory Committee on Water Data
Publication Date: September 1981
Publication Info: USBR/USGS Bulletin 17B

Summary: This guide describes the data and procedures for computing flood flow frequency curves where systematic stream gaging records of sufficient length (at least 10 years) to warrant statistical analysis are available as the basis for determination. The procedures do not cover watersheds where flood flows are appreciably altered by reservoir regulation or where the possibility of unusual events, such as dam failures, must be considered. The guide was specifically developed for the treatment of annual flood peak discharge.

59 *Title:* **Hydrologic Design for Highway Drainage in Arizona**
Author: Jencsok, E.I.
Publication Date: March 1969
Publication Info: ADOT Bridge Division

Summary: In this old report, two basic methods are described: the Rational method and the SCS method. The Rational method is recommended for urban and developed areas, while the SCS method is recommended for non-urban areas (i.e., agricultural, range, and forest lands).

60 *Title:* **Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites, 1993**
Author: Jennings, M. E., Thomas, W. O., Jr., Riggs, H. C.
Publication Date: 1994
Publication Info: USGS WRI Report 94-4002

Summary: The USGS, in cooperation with the Federal Highway Administration and the Federal Emergency Management Agency, has compiled all the current (as of September 1993) statewide and metropolitan area regression equations into a microcomputer program titled the National Flood Frequency Program. This program includes regression equations for estimating flood-peak discharges and techniques for estimating a typical flood hydrograph for a given recurrence interval peak discharge for unregulated rural and urban watersheds. This report summarizes the statewide regression equations for rural watersheds in each State, summarizes the applicable metropolitan area or statewide regression equations for urban watersheds, describes the National Flood Frequency Program for making these computations, and provides much of the reference information on the extrapolation of the variables needed to run the program.

61 *Title:* **Discharge Frequency Analysis for Alluvial Fans/Arid Regions -- Rainfall-Runoff Approach**
Land Use and Flood Damages in Arid and Semi-Arid Areas

Author: Khine, M.

Publication Date: December 1992

Publication Info: Proceedings of the Conference on Arid West Floodplain Management Issues

Summary: This paper focuses on approaches, concepts, and methods in hydrologic processes on alluvial fans and recommends a rainfall-runoff approach to develop discharge hydrographs for different frequencies over alluvial fans and other areas in arid regions. This paper describes the response of different loss rate methods in the HEC-1 computer program when applied to a watershed in Albuquerque, NM. Of all the methods investigated, the Holtan method is recommended for use in arid regions because of its flexibility and availability of the parameters.

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62 *Title:* **Drainage Criteria Manual**

Author: Kimley-Horn and Associates, Inc.

Publication Date: October 2002

Publication Info: Town of Oro Valley, Arizona

Summary: The drainage manual for Oro Valley suggests using the Rational Method for drainage basins less than 20 acres. Otherwise rainfall-runoff models such as HEC-1 and HEC-HMS should be used. This manual relies heavily on Tucson's Hydrology Manual and ADOT's Hydrology Manual.

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63 *Title:* **Reconnaissance Assessment of Erosion and Sedimentation in the Canada de los Alamos Basin, Los Angeles and Ventura Counties, California**

Author: Knott, J.M.

Publication Date: 1980

Publication Info: USGS Water Supply Paper 2061

Summary: An assessment of present erosion and sedimentation conditions in the Canada de los Alamos basin was made to aid in estimating the impact of off-road-vehicle use on the sediment yield of the basin. Impacts of off-road vehicles were evaluated by reconnaissance techniques and by comparing the study area with other off-road-vehicle sites in California. Major-storm sediment yields for the basin were estimated using empirical equations developed for the Transverse Ranges and measurements of gully erosion in a representative off-road-vehicle basin. Normal major-storm yields of 73,200 cubic yards would have to be increased to about 98,000 cubic yards to account for the existing level of accelerated erosion caused by off-road vehicles. Long-term sediment yield of the Canada de los Alamos basin upstream from its confluence with Gorman Creek, under present conditions of off-road-vehicle use, is approximately 420 cubic yards per square mile per year--a rate that is considerably lower than a previous estimate of 1,270 cubic yards per square mile per year for the total catchment area above Pyramid Lake.

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64 *Title:* **Prediction of Sediment Yield**

Author: Kothyari, U. C., Tiwari, A. K., Singh, R.

Publication Date: November 1994

Publication Info: Journal of Irrigation and Drainage Engineering, Vol. 120, No. 6, pp. 1122-1131

Summary: This paper reviews some of the existing models for predicting sediment yields and compares them to carefully collected data from experimental catchments. This existing methods include:

USLE, USLE with delivery ratio, MUSLE, and Kling's method. It was found that existing methods do not adequately account for the process of sediment delivery; hence these methods produce a less accurate prediction of sediment yield. A new method, based on routing surface erosion through time-area segments, is proposed. This method is found to predict the sediment yield more accurately.

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65 *Title:* **Hyperconcentrations, Mud and Debris Flows**
Sediment Transport Modeling
Author: Krone, R. B., Bradley, J. B.
Publication Date: 1989
Publication Info: ASCE Conf. Proceedings

Summary: This paper briefly describes the mechanical properties of mud and debris flow and hyperconcentrated stream flow materials. Through notable literature survey, the paper draws the conclusion that experience-based knowledge of mud and debris flows is sufficient to construct useful numerical models provided adequate measurements of the mechanical properties of the material is made, and provided these properties are incorporated in the model appropriately. The mechanical properties of a particle-water mixture at moderate to high concentrations depend primarily on the composition of the mixture: the particle size distribution, the presence of clay, silt minerals and dissolved salts, the concentration of particles, and on the mixture's velocity gradient history. This makes accurate measurement of these properties vital to successful numerical model development. However, measurements on actual flows are limited to laboratory reconstruction after their occurrence, but such reconstructions are important for broadening of our knowledge of their behavior and for verifying models. Continued efforts in laboratory measurements of velocity profiles and shear stresses on beds of varying roughness are necessary, particularly on mud flows.

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66 *Title:* **Robust Flood Frequency Models**
Author: Kuczera, G.
Publication Date: April 1992
Publication Info: Water Resources Research, Vol. 18, No. 2, pp. 315-324

Summary: The concept of a robust model is briefly explored. In the context of flood frequency analysis, two necessary properties of a robust model are advanced resistance and efficiency. Because of its versatility, the five-parameter Wakeby distribution can be considered a parent flood distribution.

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67 *Title:* **Engineering Methodology for Delineating Debris Flow Hazards in Los Angeles County**
Water Forum '86
Author: Kumar, S.
Publication Date: 1986
Publication Info: ASCE Conf. Proceedings

Summary: An engineering method for debris flow flood hazard delineation in Los Angeles County is discussed. The delineation procedure includes defining the transport and deposition zone, the flow expansion, the gradient of deposition, and quantity of debris that is delivered to the fan at a canyon mouth. The relative likelihood of hazard within the total fan is identified considering the influence of adjacent canyons and the effect of improvement such as debris retention facilities and conveyance systems. Given that traditional solution of providing mitigation measures using debris basins is costly for construction and maintenance, the compromise is flood plain regulation and non-structural control measures, which include zoning, land-use restriction, and flood-proofing to minimize potential damage from debris flow. The method developed in this paper sets the first step towards flood hazard mapping. For purposes of general flood plain regulation, the study focused only on formulating mapping procedures and defining relative likelihood of hazards within the inundation/deposition zone. In addition, the model development considered only unimproved, unobstructed fan area.

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68 *Title:* **Hydrology Manual for Los Angeles County Department of Public Works**

Author: Los Angeles County DPW

Publication Date: December 1991

Publication Info: Hydraulic/Water Conservation Division

Summary: The purpose of this manual is to take the engineer through the steps involved in converting rainfall to runoff in accordance with Public Works standards. Natural watercourses, floodways and culverts must be protected from the Capital Flood (50-year frequency design storm falling on a saturated watershed). Urban Flood protection (including all facilities in the developed area not covered by the Capital Flood protection) is set to a 25-year frequency design storm. There are two basic methods to convert rainfall to runoff, the Modified Rational Method and the Mountain Hydrology Method. Three simplified version of the Modified Rational Method are the Rational method (for drainage areas less than 100 acres), the Small Developed Drainage Areas Method (for drainage areas less than 10 acres only), and the Urban Flood Q Equation.

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69 *Title:* **Sedimentation Manual for Los Angeles County Department of Public Works**
Hydraulic/Water Conservation Division

Author: Los Angeles County DPW

Publication Date: June 1993

Publication Info: Hydraulic/Water Conservation Division

Summary: This manual establishes the Los Angeles County Department of Public Works' sedimentation design criteria. The procedures and standards contained in this manual were developed mostly by the Hydraulic/Water Conservation Division of Los Angeles County Department of Public Works as the need arose to design erosion control structures, sediment retention structures, and channel carrying sediment laden flows. These sediment techniques are applicable in the design of local debris basins, storm drains, retention, and detention basins, and channel projects. The Manual includes chapters on sediment production and delivery, sediment control methods (i.e. debris basins), and sediment transport (soft and hard bottom channels and drop structures).

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70 *Title:* **Sediment Yield of the Castaic Watershed, Western Los Angeles County, California**
A Quantitative Geomorphic Approach

Author: Lustig, L.K.

Publication Date: 1965

Publication Info: USGS Professional Paper 422-F

Summary: This report treats the problem of estimating, within a short period of time, the long-term sediment yield of the Castaic watershed in the general absence of hydrologic data. The estimate provided is based on a comparison of geomorphic parameters for watersheds in the San Gabriel Mountains, for which long-term sediment-yield data are available, and for the Castaic watershed.

71 *Title:* **Estimating Sediment Delivery and Yield on Alluvial Fans**
Hydraulics/Hydrology of Arid Lands (H2AL)
Author: MacArthur, R.C., Harvey, M.D., Sing, E.F.
Publication Date: 1990
Publication Info: ASCE Conf. Proceedings

Summary: This paper summarizes a Sediment Engineering Investigation (SEI) of the Caliente Creek watershed in Kern County, California to determine the watershed sediment yield upstream from a proposed flood detention reservoir located on the Caliente Fan. A two-step SEI was conducted to address the sediment yield question: (1) geomorphic analyses were conducted to determine those unique characteristics of the basin and channels important to estimating sediment yield, and (2) sedimentation analyses were conducted to determine the sediment yield in light of the findings from the geomorphic analyses. To determine the amount of sediment that could possibly enter the proposed reservoir during its design life of 100 years, both the average annual sediment yield and single event sediment yields were estimated using a variety of sediment engineering procedures reported in U.S. Army Corps of Engineers' Engineering Manual EM 1110-2-4000, "Sediment Investigation of Rivers and Reservoirs". The pros and cons of different procedures are discussed through comparison of results and efficiency evaluation of the design storage capacity of the proposed reservoir.

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72 *Title:* **Erosion and Sediment Delivery Following Removal of Forest Roads**
Author: Madej, M.A.
Publication Date: 2001
Publication Info: Earth Surface Processes and Landforms, Vol. 26, No. , pp. 175-190

Summary: Several techniques were applied to forest roads in northern California in an attempt to reduce road-related sediment input to streams. Sediment yields were estimated by measuring the void left by bank erosion or mass movement features and measuring the dimensions of the downslope, if present.

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73 *Title:* **Hydrology**
HEC-19
Author: Masch, Frank D.
Publication Date: October 1984
Publication Info: Federal Highway Administration FHWA-1P-84-15

Summary: This manual provides a synthesis of practical hydrologic methods and techniques to assist the highway engineer in the analysis and design of highway drainage structures. The manual begins with a discussion of descriptive hydrology, the surface runoff process and hydrologic data with emphasis given to the highway stream-crossing problem. The commonly used frequency distributions for estimating peak flows for basins with adequate data are discussed in detail and illustrated by examples. USGS regression equations and other methods for peak flow determinations in ungaged watersheds and in basins with insufficient data are presented with examples. Methods for developing unit hydrographs from streamflow data and by the Snyder and SCS synthetic procedures for ungaged sites are described in detail. Techniques for developing design storms and design hydrographs are given for basins with and without data. Estimate of peak flow and hydrograph development in urban watershed using the SCS methods of TR-55 and the USGS Basin Development Factor procedure are illustrated in detail. The manual concludes with a brief discussion of risk analysis and its dependence on hydrologic analysis.

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74 *Title:* **Highway Hydrology**
HDS 02, Second Edition
Author: McCuen, R.H., Johnson, P.A., Ragan, R.M.
Publication Date: October 2002
Publication Info: Federal Highway Administration FHWA-NHI-02-001

Summary: This document discusses the physical processes of the hydrologic cycle that are important to highway engineers. These processes include the approaches, methods, and assumptions applied in design and analysis of highway drainage structures. Hydrologic methods of primary interest are frequency analysis for analyzing rainfall and ungaged data, empirical methods for peak discharge estimation, and hydrograph analysis and synthesis. The document describes the concept and several approaches for determining the time of concentration. The peak discharge methods discussed include log-Pearson Type III, regression equations, the SCS graphical method (curve number method), and the rational method. The technical discussion of each peak flow approach includes urban development applications. The document presents common storage and channel routing techniques related to highway drainage hydrologic analyses. The document also describes methods used in the planning and design of stormwater management facilities. Special topics in hydrology include discussions of arid lands hydrology, wetlands hydrology, snowmelt hydrology, and hydrologic modeling, including geographic information system approaches and applications.

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75 *Title:* **Comparison of Simple Versus Complex Distributed Runoff Models on a Midsized Semiarid Watershed**
Author: Michaud, J., and Sorooshian, S.
Publication Date: March 1994
Publication Info: Water Resources Research, Vol. 30, No. 3, pp. 593-605

Summary: The increasing availability of distributed rainfall data and computational resources is providing the opportunity to use distributed models for rainfall-runoff forecasting. This paper compares the accuracy of simulations from a complex distributed model (KINEROS), a simple distributed model (based on the SCS method), and a simple lumped model (SCS method). The 150 square kilometer semiarid Walnut Gulch experimental watershed was the test site; models were validated using 24 severe thunderstorms and rain gauge densities similar to those found at flash flood warning sites. None of the models were able to accurately simulate peak flows or runoff volumes from individual events. Models showed more skill in predicting time to peak and the ratio of peak flow to volume.

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76 *Title:* **Analysis of Flow-Duration, Sediment-Rating Curve Method of Computing Sediment Yield**
Author: Miller, C.P.
Publication Date: April 1951
Publication Info: Hydrology Branch, Project Planning Division, USBR

Summary: This paper has three objectives. The first objective is to determine the procedures necessary to develop a correlation between water discharge and sediment discharge of a stream where the basic data plot in such a manner that no apparent relationship is presented. The second objective is to check the accuracy of the flow-duration, sediment-rating curve procedure for estimating sediment yield. The third objective is to examine the limitations of the sediment-rating, flow-duration estimate of the sediment yield.

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77 *Title:* **Hydrologic Approach to Prediction of Sediment Yield**
Author: Mizumura, K.
Publication Date: April 1989
Publication Info: Journal of Hydraulic Engineering, Vol. 115, No. 4, pp. 529-535

Summary: By separating and computing the overland flow component from the total river flow discharge, the suspended sediment discharge can be estimated by an exponential relation between the overland flow component and the suspended sediment discharge. The result is found to be in good agreement with the observed data. This formulation is based on the consideration that the suspended sediment is yielded and transported principally by the overland flow.

78 *Title:* **Mixed Population Frequency Analysis**
Author: Morris, E.C.
Publication Date: April 1982
Publication Info: U.S. Army Corps of Engineers, Hydrologic Engineering Center TD-17

Summary: The training document provides a set of guidelines on the development of frequency curves from annual peak discharges separated in two populations. A combined-population frequency approach is typically considered when the frequency curves derived from mixed population exhibit breaks, which are often caused by several large events that depart significantly from the trend of the rest of the data. These large events are frequently produced by hydrologic phenomena such as hurricanes in a normal rainfall series, rainfall events in a snowmelt series, or thunderstorm events in winter rainstorm series. The primary motivation behind a combined-population analysis is to provide a better fit between the analytically derived distributions and the plotting positions that can be obtained with a mixed-population frequency analysis. An important consideration is the independence of events. If the data in one of the series is not independent of data in the other series, then a coincident frequency analysis rather than a combined-population frequency analysis is warranted.

79 *Title:* **Highway Drainage Design Manual**
Hydrology
Author: NBS/Lowry Engineers and Planners, Inc.
Publication Date: March 1993
Publication Info: FHWA and Arizona DOT FHWA-AZ93-281

Summary: Two analytic methods are presented to determine design discharges, and those two methods are to be used mainly for ungaged watersheds. The two analytic methods are: the Rational Method and rainfall-runoff modeling for any size drainage area. The rainfall-runoff modeling guidance is structured to be compatible with the HEC-1 Flood Hydrology program. A flood frequency procedure is provided for computing flood magnitude-frequency relations where systematic stream gaging records of sufficient length are available. Three indirect methods are presented for estimating flood peak discharges.

80 *Title:* **Highway Drainage Design Manual**
Hydrology - Metric Edition
Author: NBS/Lowry Engineers and Planners, Inc.
Publication Date: December 1994
Publication Info: FHWA and Arizona DOT FHWA-AZ94-442

Summary: Two analytic methods are presented to determine design discharges, and those two methods are to be used mainly for ungaged watersheds. The two analytic methods are: the Rational Method and rainfall-runoff modeling for any size drainage area. The rainfall-runoff modeling guidance is structured to be compatible with the HEC-1 Flood Hydrology program. A flood frequency procedure is provided for computing flood magnitude-frequency relations where systematic stream gaging records of sufficient length are available. Three indirect methods are presented for estimating flood peak discharges.

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81 *Title:* **Drainage Manual**

Author: Nevada Department of Transportation

Publication Date: December 2005

Publication Info:

Summary: The manual outlines several available hydrologic methods acceptable to NDOT: the Rational Method, a statistical flood frequency analysis, regression equations, and synthetic modeling.

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82 *Title:* **Assessment of Commonly Used Methods of Estimating Flood Frequency**

Author: Newton, D.W., Herrin, J.C.

Publication Date: 1982

Publication Info: Trans. Research Record 896, Vol. , No. , pp. 10-30

Summary: The paper summarizes a study conducted to determine the most accurate and consistent procedures for peak flood frequencies for ungaged watersheds in the Tennessee Valley. The results show significant differences in performance when procedures were evaluated by using the criteria of accuracy, reproducibility, and practicality. A classification scheme with eight categories was adopted for categorizing procedures based on the assumptions made and methods used for estimating peak flow frequencies. These categories are: statistical estimation of peak flows for a given exceedance probability, statistical estimates of moments (e.g., mean, variance, and skew), index flood, transfer methods, empirical equations, single storm event, multiple discrete events, and continuous records. The pilot test consisted of five independent estimates of peak flow frequency for the 1-, 10-, and 50-percent-chance floods using as many as ten different procedures including two complex watershed modeling procedures namely, the SCS Technical Release (TR) 20 and U.S. Army Corps of Engineers Flood Hydrograph Package HEC-1. The standard estimate used to evaluate accuracy was the log-Pearson Type III flood-frequency one. Performance comparisons are made using box plots. Sensitivity analyses on the form of the prediction equations were performed to assess the impact of parameter variability on flow estimates, and thus the procedure performance.

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83 *Title:* **Depth-Area Ratios in the Semi-Arid Southwest United States**

Author: NOAA

Publication Date: August 1984

Publication Info: NOAA National Weather Service Technical Memorandum NWS HYDRO-40

Summary: The memorandum presents estimates of geographically fixed depth-area ratios for Arizona and western New Mexico. The study relies on a methodology for computing depth-area ratios from dense network data. Modification of the approach was necessary to extend the results to sparse regions. The objective of the study was to derive depth-area ratios in a form suitable for engineering use for a substantial portion of Arizona and New Mexico. This involved, a) developing depth-area ratios for Walnut Gulch in southeastern Arizona for 24 hour, a duration not included in previous studies, b) extending the Walnut Gulch ratios to larger areas than the original, and c) defining a region over which the Walnut Gulch depth-area ration curves apply and additional regions over which they apply with modification. The 24-hour duration is necessary for maximum utility in hydrologic procedures of the Soil Conservation Service which uses 24 hour as the base duration, and a tool for exploring within-region and inter-region depth-area ratio variations. The TR 24 method of depth-area ratio analysis was followed with the Walnut Gulch data. Statistical analysis indicated that depth-area ratios in the Upper Rio Grande basin near Albuquerque are similar to those for Walnut Gulch, and different from those at Alamogordo Creek (from a past study) in eastern New Mexico.

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84 *Title:* **Urban Hydrology for Small Watersheds**

Author: NRCS

Publication Date: June 1986

Publication Info: Natural Resources Conservation Service Technical Release 55

Summary: This revised technical release presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. The procedures described are applicable to small watersheds, especially urbanizing watersheds. First issued by the Soil Conservation Service (SCS) in January 1975, TR-55 incorporates current SCS procedures. The major revisions and additions are: 1) A flow chart for selecting the appropriate procedure; 2) Three additional rain distributions; 3) Expansion of the chapter on runoff curve numbers; 4) A procedure for calculating travel times of sheet flow; 5) Deletion of a chapter on peak discharges; 6) Modification to the Graphical Peak Discharge method and Tabular Hydrograph method; 7) A new storage routing procedure; 8) Features of the TR-55 computer program; and 9) Worksheets.

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85 *Title:* **SCS Engineering Field Handbook**

Chapter 2: Estimating Runoff and Peak Discharges

Author: NRCS

Publication Date: June 1990

Publication Info: Natural Resources Conservation Service 210-VI-NEH-650.02

Summary: The field handbook presents the SCS Curve Number procedure based on hydrologic soil groups for estimating runoff and peak discharges from small rural watersheds for use in designing soil and water conservation measures. The procedure is valid for watershed areas between 1 and 2,000 acres. Limitations of this procedure are discussed.

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86 *Title:* **National Engineering Handbook**

Hydrology-Part 630

Author: NRCS

Publication Date: September 1997

Publication Info: Natural Resources Conservation Service

Summary: The handbook, intended primarily for Natural Resources Conservation Service (NRCS) engineers and technicians, presents material needed to carry out tasks in natural resource conservation and flood prevention. Part 630, Hydrology, contains methods and examples for: 1) studying the hydrology of watersheds; 2) solving special hydrologic problems that arise in planning watershed protection and flood prevention projects; 3) preparing working tools needed to plan or design structures for water use, control, and disposal; and training personnel newly assigned to activities that include hydrologic studies. The handbook consists of 22 chapters with notable sections on statistical methods in hydrology, hydrologic soil groups, land use, stage-discharge relationships, watershed yields, design hydrographs, and flood routing.

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87 *Title:* **Riverside County Hydrology Manual**

Author: Peairs, Frank, J.

Publication Date: April 1978

Publication Info: Riverside County Flood Control and Water Conservation District

Summary: The purpose of the Manual is to document design hydrology methods and criteria currently used by the Riverside County Flood Control and Water Conservation District. The two primary methods used to determine design discharges are the Rational method (for areas less than 300-500 acres) and the Synthetic Unit Hydrograph method (for watersheds in excess of these limits). The manual also provides several methods to estimate debris production in Riverside County. Precipitation data is based on NOAA Atlas 2.

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88 *Title:* **Distinguishing Between Debris Flows and Floods from Field Evidence in Small Watersheds**

Author: Pierson, Thomas C.

Publication Date: January 2005

Publication Info: USGS Fact Sheet 2004-3142

Summary: This short paper attempts to distinguish debris flows and floods from field evidence in small watersheds. Post-flood indirect measurement techniques to back-calculate flood magnitude are not valid for debris flows, which commonly occur in small steep watersheds during intense rainstorms. This is because debris flows can move much faster than floods in steep channel reaches and much slower than floods in low-gradient reaches. In addition, debris-flow deposition may drastically alter channel geometry in reaches where slope-area surveys are applied. Because high-discharge flows are seldom witnessed and automated samplers are commonly plugged or destroyed, reliance on field evidence becomes necessary. Key points to remember in field evaluations are: 1) consider all the evidence available such as stratigraphic, sedimentologic, and geomorphic variables, and effects on vegetation and structures; 2) examine channel over a wide area and not just at gage sites; and 3) keep in mind that high-discharge events may involve different flow types with latest part of flow possibly having the potential to modify evidence left by an earlier part of flow.

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89 *Title:* **Pinal County Drainage Manual - Volume I (Design Criteria)**

Author: Pinal County Department of Public Works

Publication Date: August 2004

Publication Info:

Summary: The revised draft design criteria dated August 2004 is presented. Volume 1 of the Pinal County Drainage Manual establishes minimum standards and criteria for the design of drainage and storm water management facilities within unincorporated Pinal County, Arizona. The purpose of this drainage manual is to establish general drainage policies, provide the minimum criteria, and to serve as an aid in the design of drainage and stormwater management facilities within Pinal County. The design criteria, if adopted by the local jurisdiction entities, will establish uniform drainage policies and practices throughout the County.

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90 *Title:* **Pinal County Drainage Manual - Volume II (Design Methodologies and Procedures)**
Author: Pinal County Department of Public Works
Publication Date: August 2004
Publication Info:

Summary: Volume 2 of the Pinal County Drainage Manual is intended to serve as an aid in the design of drainage and stormwater management facilities. The manual provides a convenient source of technical information and presents methodologies and procedures acceptable to the County. The major topics included in the design procedures are: 1) street drainage; 2) storm drains and catch basins; 3) culverts, bridges, and at-grade drainage crossings; 4) inlets and outlets for culverts; 5) inverted siphons; 6) open channel design; 7) erosion and sedimentation; and 8) hydraulic structures.

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91 *Title:* **Runoff Curve Number: Has it Reached Maturity?**
Author: Ponce, V.M., and Hawkins, R.H.
Publication Date: January 1996
Publication Info: Journal of Hydrologic Engineering, Vol. 1, No. 1, pp. 11-18

Summary: The conceptual and empirical foundations of the runoff curve number method are reviewed, and the perceived advantages and disadvantages of this method are discussed.

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92 *Title:* **Engineering Hydrology**
Principles and Practices
Author: Ponce, Victor Miguel
Publication Date: 1989
Publication Info: Prentice Hall

Summary: This book aims to provide a balanced treatment of basic principles and current practices in engineering hydrology. The author relies on a catchment-scale framework (i.e. presenting procedure applicable to small catchments first and then following with mid-size and large-scale catchments), allowing the coverage of the material to proceed from the rational method to the unit hydrograph and routing methodologies. The book includes chapters on hydrologic cycle, hydrologic principles and measurements, hydrology of small and mid-size catchments, frequency and regional analysis, subsurface water, and snow hydrology.

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93 *Title:* **Chapter C3: Computation of Fluvial-Sediment Discharge**
Book 3, Applications of Hydraulics
Author: Potterfield, G.
Publication Date: 1972
Publication Info: USGS Techniques of Water-Resources Investigations B3-C3

Summary: This report is one of a series concerning the concepts, measurement, laboratory procedures, and computation of fluvial-sediment discharge. Material in this report includes procedures and forms used to compile and evaluate particle-size and concentration data, to compute fluvial-sediment discharge, and to prepare sediment records for publication.

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94 *Title:* **Erosion and Sediment Yield Methods**
Report of the Water Management Subcommittee

Author: PSIAC

Publication Date: April 1974

Publication Info: Pacific Southwest Inter-Agency Committee

Summary: The methods available to estimate on-site erosion and sediment yield from small watersheds are discussed based on an extensive literature search and through correspondence with agencies in water resources and sedimentation research program in the Pacific Southwest area to ascertain the procedures in use. In spite of extensive bibliography of published material on erosion and sedimentation, the number of methods was narrowed to twelve. Six of the methods provide estimates of on-site erosion and six provide estimates of sediment yield in a stream draining a small natural watershed.

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95 *Title:* **Analysis of Sediment Production from Two Small Semiarid Basins in Wyoming**

Author: Rankl, J. G.

Publication Date: 1987

Publication Info: USGS Water Resources Investigations 85-4314

Summary: The purpose of the study described by this report was to establish a relation between sediment production, rainfall, and runoff to determine any significant difference in basin runoff and sediment production that can be attributed to surface mining. A secondary objective was to determine the relative importance of upland erosion and channel erosion as a source of sediment. Emphasis was placed on the systematic collection of sediment data to meet the objectives of the study. On unmeasured streams, Colby's (1957) method was used to estimated the sediment yield.

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96 *Title:* **A Summary of Methods for the Collection and Analysis of Basic Hydrologic Data for Arid Regions**

Author: Rantz, S.E., Eakin, T.E.

Publication Date: February 1971

Publication Info: USGS Open-File Report 72-305

Summary: This USGS Water Resources Division report summarizes and discusses the then current methods of collecting and analyzing the data required for a study of the basic hydrology of arid regions. The fundamental principles behind the methods are similar to studies applicable to humid regions, but in arid regions the infrequent occurrence of precipitation, the great variability of the many hydrologic elements, and the inaccessibility of most basins usually make it economically infeasible to use conventional levels of instrumentation. For this, hydrologic studies in the arid regions are commonly of reconnaissance type with more costly detailed studies generally restricted to experimental basins and to those basins that have major economic significance. The conclusions reached from a consideration of previously reported methods are interspersed in this report where appropriate.

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97 *Title:* **Flood Frequency Methods for Arizona Streams**

State of the Art

Author: Reich, B.M.

Publication Date: October 1988

Publication Info: FHWA and Arizona DOT FHWA-AZ88-801

Summary: This report discusses various aspects of previous, present, and future methodologies for flood frequency analysis. Means for developing estimates of flood peaks that have specified rare probabilities of occurring at gaged streams sites are described. Problems and means of estimating design flood at ungaged sites are described, including need for new short duration rainfall intensities. Emphasis on arid zone difficulties and promising new approaches are stressed.

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98 *Title:* **Sediment and Erosion Design Guide**
Author: Resource Consultants & Engineers, Inc.
Publication Date: November 1994
Publication Info: Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA)

Summary: The purpose of this manual is to provide guidance for the analysis of sediment areas and arroyos in the Albuquerque metropolitan area for use in establishing an erosion limit line, which would have low possibility of being disturbed by erosion, scour, or meandering or a natural arroyo. Arroyos (or gullies) are ephemeral flow stream channels characterized by steeply sloping or vertical banks of fine sedimentary material and flat, generally sandy beds. The manual also contains criteria for placement of erosion barriers that may accomplish the purpose of maintaining natural arroyos while protecting adjacent properties. Notable sections are those addressing channel dynamics and sediment transport, lateral stability and countermeasure criteria for erosion control.

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99 *Title:* **Techniques of Water Resources Investigations of the United States Geological Survey**
Some Statistical Tools in Hydrology
Author: Riggs, H. C.
Publication Date: 1968
Publication Info: USGS TWRI Book 4-Chapter A1

Summary: This report provides detailed procedures on how to perform a regression analysis. It describes the analysis of variance and covariance and discusses the characteristics of hydrologic data.

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100 *Title:* **Techniques of Water Resources Investigations of the United States Geological Survey**
Frequency Curves
Author: Riggs, H. C.
Publication Date: 1968
Publication Info: USGS TWRI Book 4-Chapter A2

Summary: This manual describes graphical and mathematical procedures for preparing frequency curves from samples of hydrologic data. It also discusses the theory of frequency curves, compares advantages of graphical and mathematical fitting, suggests methods of describing graphically defined frequency curves analytically, and emphasizes the correct interpretations of a frequency curve.

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101 *Title:* **Techniques of Water Resources Investigations of the United States Geological Survey**
Regional Analyses of Streamflow Characteristics
Author: Riggs, H. C.
Publication Date: 1973
Publication Info: USGS TWRI Book 4-Chapter B3

Summary: This manual describes two different methods for estimating flood peaks: 1) the index-flood method and 2) the multiple regression method. The manual also discusses how to perform a regional analysis using these two methods. A regional analysis allows the flow characteristics for a gaged site to be extended to ungaged sites.

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102 *Title:* **Methods for Estimating the Magnitude and Frequency of Floods in Arizona**
Author: Roeske, R.H.
Publication Date: September 1978
Publication Info: USGS Open-File Report 78-711

Summary: Regression equations for estimating flood magnitudes at ungaged sites for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years were developed for six flood-frequency regions. The equations relate flood magnitudes to one or more of the following statistically independent variables: size of the drainage basin, mean basin elevation, and mean annual precipitation. The regression equations apply to streams that are not affected significantly by regulation, diversion, or urbanization.

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103 *Title:* **Drainage Design Manual for Maricopa, Arizona**
Hydrology
Author: Sabol, G.V., Rumann, J.M., Khalili, D., Waters, S.D., Lehman, T., Gerlach, R.M., Motamedi, A.
Publication Date: November 2003
Publication Info: Flood Control District of Maricopa County

Summary: The objective of this Hydrology Manual is to provide technical procedures for the estimation of flood discharges for the purpose of designing stormwater drainage facilities in Maricopa County. Two methodologies are defined for the development of design discharges: the Rational Method, and rainfall-runoff modeling using a design storm. For small, urban watersheds, less than 160 acres and fairly uniform land-use, the Rational Method is acceptable. Use of this method will only produce peak discharges and runoff volumes and this method should not be used if a complete runoff hydrograph is needed, such as for routing through detention facilities. For larger, more complex watersheds or drainage networks, a rainfall-runoff model should be developed. The Hydrology Manual provides guidance in the development of such a model and the estimation of the necessary input parameters to the model. The manual also provides indirect methods intended to be used as confidence checks and verification of the reasonableness of the results obtained from the two methodologies discussed above.

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104 *Title:* **Comparison of Design Rainfall Criteria for the Southwest**
Hydraulics/Hydrology of Arid Lands (H2AL)
Author: Sabol, G.V., Stevens, K.A.
Publication Date: 1990
Publication Info: ASCE Conf. Proceedings

Summary: The paper presents results of a study in the desert southwest using four combinations of design rainfall criteria in deterministic rainfall-runoff models using the HEC-1 Flood Hydrograph Package. The four design rainfall criteria are 1) hypothetic storm distribution with NOAA Atlas 2 depth-area reduction curve (HYP), 2) Soil Conservation Service Type II storm distribution with the NOAA Atlas 2 depth-area reduction curve (SCS), 3) Hydrometeorological Report No. 49 design rainfall criteria (HMR), and 4) Maricopa County hydrologic design manual (MC). The results indicate that some of the more commonly used design rainfall criteria may not adequately represent the rainfall characteristics of the southwest. Notable observations are: 1) The depth-area reduction curve in NOAA Atlas 2 was deemed inappropriate for local storms in the southwest. The hypothetical rainfall distribution with NOAA Atlas 2 depth-reduction curve may result in overestimation of design discharge for watersheds larger than about 10 square miles; 2) The SCS Type II distribution with the NOAA Atlas 2 depth-area reduction curve may result in underestimation of design discharges for watersheds smaller than 25 square miles and overestimation for watersheds larger than 100 square miles; 3) Design rainfall criteria based on the analysis of regional data and historic storms are superior to aforementioned generalized criteria. Both HMR and the MC criteria follow this concept.

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105 *Title:* **San Diego County Hydrology Manual**
Author: San Diego County
Publication Date: June 2003
Publication Info: Department of Public Works, Flood Control Section

Summary: The purpose of the Manual is to provide an uniform procedure for flood and stormwater analysis within San Diego County. Two methods for analyzing the runoff response are presented: the Rational Method, which is recommended for drainage areas up to approximately 1 square mile in size, and the NRCS Hydrologic Method (Unit Hydrograph), for areas greater than a square mile. For areas less than a square mile but with junctions of independent drainage systems, the Modified Rational Method should be used. New maximum overland flow lengths and initial time of concentration limits replace the procedure included in the 1971 Hydrology Manual of including a 10 minute value to be added to the Initial Time of Concentration developed using the Kirpich formula. The precipitation pattern is based on a nested storm pattern from HEC TD-15. The SDUH Peak Discharge program is available to prepare the rainfall distribution, calculate excess rainfall, and prepare the unit hydrograph ordinates.
Section 5 provides an outline for the prediction of sedimentation yield that occurs during rainfall events in a study area.

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106 *Title:* **Magnitude and Frequency of Urban Floods in the United States**
Author: Sauer, V. B., Thomas, W. O., Jr., Stricker, V. A., Wilson, K. V.
Publication Date: 1982
Publication Info: Trans. Research Record 896, Vol. , No. , pp. 30-39

Summary: This paper summarizes the results of a study undertaken by USGS to make a nationwide survey of urban flood frequency. The study was completed in three phases: 1) literature review on urban flood studies; 2) compilation of nationwide database of flood frequency characteristics, topographic and climate characteristics, land use variables, and indices of urbanization; and 3) data analysis for the purpose of defining estimating techniques that can be extended in ungaged urban areas. An appraisal of all watersheds resulted in a final list of 269 watersheds that met the following selection criteria: 1) 15% of any watershed had to be impervious from urban developments; 2) Availability of reliable flood frequency data; and 3) Change in development less than 50% during the period of flood data, termed “relatively constant urbanization.” Two primary sets of flood frequency estimates for selected recurrence intervals were defined for each station: 1) an estimated flood frequency relation for urbanized basin during a period of constant urbanization, and 2) the estimated relation for an equivalent rural basin. Peak discharges were estimated for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals by using Log-Pearson Type III procedure. In the third phase of the study urban flood magnitude and frequency were related to watershed characteristics to estimate the same for ungaged watersheds. The paper goes on to describe in detail the limitations of regression equations developed based on the utility of basin parameters.

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107 *Title:* **Flood Characteristics of Urban Watersheds in the United States**

Author: Sauer, V. B., Thomas, W. O., Jr., Stricker, V. A., Wilson, K. V.

Publication Date: 1983

Publication Info: USGS Water Supply Paper 2207

Summary: Three sets of regression equations were developed to estimate flood discharges for ungaged sites for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. Two sets of regression equations are based on seven independent parameters and the third is based on three independent parameters. The only difference in the two sets of seven-parameter equations is the use of basin lag time in one and lake and reservoir storage in the other. Of primary importance in these equations is an independent estimate of the equivalent rural discharge for the ungaged basin. The equations adjust the equivalent rural discharge to an urban condition. The primary adjustment factor, or index of urbanization, is the basin development factor, a measure of the extent of development of the drainage system in the basin. This measure includes evaluations of storm drains (sewers), channel improvements, and curb-and-gutter streets.

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108 *Title:* **Preliminary Flood Frequency Relations and Summary of Maximum Discharges in New Mexico**

A Progress Report

Author: Scott, A.G.

Publication Date: June 1971

Publication Info: USGS Open-File Report 71-251

Summary: The magnitude and frequency of floods is defined regionally for streams in New Mexico. An analysis was made, using multiple-regression techniques, relating flood peaks of 2, 5, 10, 25, and 50-year recurrence intervals to selected physical and climatic basin characteristics. The state was divided into three flood regions, and the resulting equations and associated standard error of prediction are presented for each of these regions. In addition, the maximum observed discharges at regular and crest-stage gaging stations, and all peak discharges by indirect measurements at miscellaneous sites are presented in tabular and graphical form.

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109 *Title:* **Erosion and Sediment Yields in the Transverse Ranges, Southern California**

Author: Scott, K.M., and Williams, R.P.

Publication Date: 1978

Publication Info: USGS Professional Paper 1030

Summary: The most logical approach to estimation of erosion rates in the Transverse Ranges is using an empirical correlation of actual sediment yields on the basis of watershed characteristics. This study will use the same type of data as the studies by Ferrell (1959) and Tatum (1965) -- actual sediment yields from debris basins in the eastern Transverse Ranges in Los Angeles County -- but will attempt to modify the predictive results to a more variable range of conditions, especially to those that exist in the western Transverse Ranges of Ventura County.

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110 *Title:* **Sedimentation in the Piru Creek Watershed, Southern California**

Sedimentation in Small Basins

Author: Scott, K.M., Ritter, J.R., and Knott, J.M.

Publication Date: 1968

Publication Info: USGS Water Supply Paper 1798-E

Summary: The probable sediment yield of the Piru Creek basin above Pyramid Rock, site of a proposed reservoir on Piru Creek upstream from Santa Felicia Reservoir, is 225 acre-feet per year, or 0.79 acre-foot of sediment per square mile per year. The yield was determined by applying a basin-size correction to the sediment yield of the entire basin. Measurements of suspended sediment indicate that 570,000 tons, a volume of 504 acre-feet, were transported past the Pyramid damsite during calendar year 1965. November and December 1965 constituted one of the most intense storm periods in southern California history, and the quantity of sediment transported during 1965 can be considered to represent the expectable maximum. The yield for 1965 confirms the long-term estimate of sediment yield as being substantially and unexpectedly less than that of surrounding watersheds.

Comparable figures for sediment yield were obtained from other analyses of sedimentation in basins of the Transverse Ranges and by correlation of sediment yields in other basins. Multiple-regression equations were calculated using sedimentation records of seven nearby reservoirs.

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111 *Title:* **Design Manual for Engineering Analysis of Fluvial Systems**

Author: Simons, Li, and Associates

Publication Date: March 1985

Publication Info: Arizona Department of Water Resources

Summary: This old SLA report provides a summary of the rational method, the NRCS TR-55 method, the USGS flood-frequency method, and other regionalized hydrology methods.

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112 *Title:* **Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona**

Author: Simons, Li, and Associates, Inc.

Publication Date: July 1998

Publication Info: Tucson, Arizona

Summary: In Chapter IV, a simple step-by-step procedure for estimating 2-yr, 5-yr, 10-yr, 25-yr, 50-yr, and 100-yr flood peaks and flood hydrographs for watershed areas located within the City of Tucson which are less than 10 square miles is presented. Prior to applying the procedure, the user should be aware that flood peaks have been determined for most watersheds located within the corporate limits of the City of Tucson during the formulation of the Tucson Stormwater Management Study (TSMS). Before proceeding with the estimation of flood peaks, the user should check to see if TSMS flood peaks already exist. When the TSMS hydrology is nonexistent, users should following the City of Tucson's Flood Peak Estimator Procedure, which is based on the procedure in Pima County Flood Control District's Hydrology Manual.

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113 *Title:* **Olancha Debris Flow: An Example of an Isolated Damaging Event**

Hydraulics/Hydrology of Arid Lands (H2AL)

Author: Slosson, J. E., Slosson, T. L.

Publication Date: 1990

Publication Info: ASCE Conf. Proceedings

Summary: A case history of an isolated flood/debris flow in California is discussed. The sub-tropical storm driven event damaged a portion of the Los Angeles Department of Water and Power Owens Valley aqueduct and threatened serious damage to U.S. highway 395 near Olancha, along approximately three miles of the eastern front of the Sierra Nevada Mountain range. This storm, with its isolated and great damaging effects, provides a good text book example of the nature of sub-tropical storms that extend over desert areas of the Southwest. The existence of an isolated storm cell was caused by topographic (orographic) controls, air mass directional flow patterns, and local temperature variation related to convective heating. These weather factors, among other physical factors, should be considered in the planning and design of critical lifelines. While each past event of this kind has been found to unique, the authors indicate similarities between them. The authors suggest that a method of delineating and predicting what can happen on an alluvial fan should be compensated with design which would require data and mapping on a site-by-site basis to fully analyze the potential for success.

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114 *Title:* **Reservoir Sedimentation**
Technical Guideline for Bureau of Reclamation
Author: Strand, R.I., and Pemberton, E.L.
Publication Date: October 1982
Publication Info: Sedimentation and River Hydraulics Section, USBR

Summary: This publication provides a brief summary of the various methodologies that can be used to calculate sediment yield.

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115 *Title:* **Application of Generalized Least Squares in Regional Hydrologic Regression Analysis**
Selected Papers in the Hydrologic Sciences
Author: Tasker, G.D., Eychaner, J.H., and Stedinger, J.R.
Publication Date: December 1986
Publication Info: USGS Water Supply Paper 2310

Summary: Alternative methods for estimating parameters of a regional regression of the 100-year peak discharge are considered. A generalized least-squares (GLS) technique that accounts for cross-correlated data of different record lengths was compared with the commonly used ordinary least-squares (OLS) method. The GLS technique is shown to be better than the OLS technique in terms of average variance prediction on the basis of a split-sample study of 89 gages in Pima County, AZ.

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116 *Title:* **Sediment Yields in Coastal Southern California**
Author: Taylor, B.D.
Publication Date: January 1983
Publication Info: Journal of Hydraulic Engineering, Vol. 109, No. 1, pp. 1983

Summary: In southern California the delivery of inland sediments to the coast is important for shoreline stability and the preservation of natural beach areas. During the past several decades, changes in land use and the construction of water conservation and flood control structures have materially affected natural sediment movements and coastal deliveries. To provide a basis for regional sediment management, a study has been undertaken at the California Institute of Technology to quantify natural sediment movements and man's effect on these processes. As a first step in this study, sediment yields from inland areas have been estimated using regression equations.

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117 *Title:* **Floodplain Management in the Desert?!**
Arid Regions Floodplain Management 8th Biennial Conference
Author: Teal, Martin J., ed.
Publication Date: January 1999
Publication Info: Association of State Floodplain Managers, Arizona Floodplain Management Association

Summary: This book contains the papers presented during the Arid Regions Floodplain Management 8th Biennial Conference held in Las Vegas, NV on January 20-22, 1999. "Use of historic flood data for flood insurance studies" discusses the importance of historic floods in assessing flood frequency in arid regions where there is a high degree of variability in rainfall and flood data. "Using real information to evaluate the magnitude and frequency of flash floods in small desert watersheds" proposed an alternative approach to statistical analyses of sparse data in small arid watersheds. Several papers discuss alluvial fans watershed modeling, floodplain evaluations of restoration projects and stream stability, and the use of Geographical Information System in Hydrologic Analysis.

118 *Title:* **Methods for Estimating Peak Discharge and Flood Boundaries of Streams in Utah**
Author: Thomas, B.E., and Lindskov, K.L.
Publication Date: 1983
Publication Info: USGS Water Resources Investigation 83-4129

Summary: Equations for estimating 2-, 5-, 10-, 25-, 50-, and 100-year peak discharges and flood depths at ungaged sites in Utah were developed using multiple-regression techniques. Ratios of 500- to 100-year values also were determined. The peak-discharge equations are applicable to unregulated streams and the flood-depth equations are applicable to unregulated flow in natural stream channels. Drainage area and mean basin elevation are the two basin characteristics needed to use these equations.

119 *Title:* **Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States**
Author: Thomas, B.E., Hjalmarson, H.W., and Waltemeyer, S.D.
Publication Date: 1994
Publication Info: USGS Open-File Report 93-419

Summary: This publication is out of date. Please see USGS Water Supply Paper 2433.

120 *Title:* **A uniform technique for flood frequency analysis**
Author: Thomas, W.O.
Publication Date: July 1985
Publication Info: ASCE Journal of Water Resources Planning and Management, Vol. 111, No. 3, pp. 321-337

Summary: This paper gives a brief historical review of the development of the U.S. Water Resources Council (WRC) published bulletins (Bulletin 15, 17, 17A, 17B), and the motivation and justification for the adoption of an uniform technique for estimating floodflow frequencies for gaged watersheds. Special emphasis is given to Bulletin 17B, the current guidelines used by Federal agencies. Specific techniques examined are the development of regional skew, weighting of regional and station skew, the basis for the low- and high-outlier tests, and the basis for the adjustment of frequency curve using historical information.

121 *Title:* **An Approach for Evaluating Flood Frequency Estimates for Ungaged Watersheds**
Bridging the Gap
Author: Thomas, W.O., Jr., Grimm, M.M., McCuen, R.H.
Publication Date: 2001
Publication Info: ASCE Conf. Proceedings

Summary: Floodplain management and design of hydraulic structures, such as bridges and culverts, require flood frequency estimates for various return periods at ungaged watersheds. These estimates are usually made with regional regression equations or rainfall-runoff models. The regional regression equations are developed by relating flood discharges, such as the 100-year flood discharge, to watershed and climatic characteristics at gaging stations. For application at an ungaged site, one must determine the applicable watershed and climatic characteristics. Rainfall-runoff models are often based on a design storm where rainfall amounts are taken from applicable rainfall atlases and a time distribution is assumed. These two different approaches can provide widely differing estimates of the design discharge. Often flood discharges are available from both regression equations and rainfall-runoff models prior to developing the floodplain boundaries or designing the hydraulic structure. This paper describes an approach for comparing estimates from regression equations and rainfall-rainfall models to gaging station data and determining the most reasonable flood frequency estimate.

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122 *Title:* **Design Rainfall Distributions for the State of Wyoming**

Author: Tyrrell, P.T., and Hasfurther, V.R.

Publication Date: August 1983

Publication Info: Wyoming Water Research Center, Dept. of Civil Engineering, University of Wyoming WWRC 8

Summary: This research report from the Wyoming water Research Center discusses the necessity of regionalized rainfall distribution development in support of the design of hydraulic structures. The report refers to studies in the hydrology literature documenting the effects of time distribution of rainfall in runoff hydrographs. Because of the existence of this relationship, the report stresses on the need to study storm rainfall for accurate flood prediction regardless of other variables that also influence the runoff process. The report outlines the method to develop dimensionless design mass curve for general storms and thunderstorms for the semi-arid regions of the State of Wyoming. Due to lack of continuously recorded rainfall data, discrete data were used. Hourly and 5-minute incremental precipitations data were used in general storm and thunderstorm analysis, respectively. Parameters used in describing storm rainfall are: storm duration, storm volume, storm intensity, percent time to peak intensity, and pattern index. Linear regression and analysis of variance (ANOVA) tests performed on the rainfall data lead to the following conclusions: 1) a difference in the time distribution of thunderstorm rainfall compared to general storm rainfall exists for the entire State of Wyoming, 2) the time distribution of both thunderstorm and general storms is not dependent upon the drainage basin in which the storms occur, and 3) no relationship exists between time distribution characteristics and duration of general storms or thunderstorms.

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123 *Title:* **Standard Project Flood Determination**

Author: U.S. Army Corps of Engineers

Publication Date: March 1965

Publication Info: EM 1110-2-1411

Summary: This bulletin reviews briefly principal classes of flood analyses and estimates involved in the planning and design of flood control and multiple-purpose projects, with the primary objectives of indicating the general application and purposes of Standard Project Flood Estimates. Generalized rainfall criteria and recommended procedures for the computation of standard project storm rainfall and rainfall-excess quantities for small drainage basins (classified as approximately 1,000 square miles and less) located east of 105° longitude, are presented, with a concise explanation of their derivation. Procedures for derivation of SPS and SPF estimates for large drainage basins (exceeding approximately 1000 square miles) are discussed and illustrated.

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124 *Title:* **Sedimentation Investigations of Rivers and Reservoirs**
Author: U.S. Army Corps of Engineers
Publication Date: December 1989
Publication Info: EM 1110-2-4000

Summary: Chapter 3 presents guidance on the selection and application of procedures for calculating sediment yield. Procedures are identified, positive and negative attributes of methods are presented in terms of the type of project for which the yield is needed, and important checkpoints in the use of the methods are presented. The sequence in which the methods are presented indicates the reliability of results, from most reliable to least reliable. This chapter does not describe all calculations in detail. Methods covered include direct measurement methods, regional methods, and mathematical methods. Direct measurement methods published long-term daily discharge records, period yield sediment load accumulation, flow-duration sediment discharge rating curve method, and flood water sampling. Regional methods include maps, graphs, and equations based on definable parameters. Mathematical methods include sediment transport functions, sediment delivery ratios, and computer models such as STORM.

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125 *Title:* **Hydrologic Frequency Analysis**
Author: U.S. Army Corps of Engineers
Publication Date: March 1993
Publication Info: EM 1110-2-1415

Summary: This manual provides guidance in applying statistical principles to the analysis of hydrologic data for U.S. Army Corps of Engineers Civil Works activities. The text illustrates, by example, many of the statistical techniques appropriate for hydrologic problems. The basic theory is usually not provided, but references are provided for those who wish to research the techniques in greater detail.

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126 *Title:* **Flood Runoff Analysis**
Engineer Manual
Author: U.S. Army Corps of Engineers
Publication Date: August 1994
Publication Info: EM 1110-2-1417

Summary: This manual describes methods for evaluating flood-runoff characteristics of watersheds. Guidance is provided in selecting and applying such methods to support the various investigations required for U.S. Army Corps of Engineers (USACE) civil works activities. The manual is organized into four parts: 1) problem definition and selection of methodology, 2) hydrologic Analysis, 3) methods for flood-runoff analysis, and 4) engineering applications.

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127 *Title:* **Application of Methods and Models for Prediction of Land Surface Erosion and Yield**
Author: U.S. Army Corps of Engineers
Publication Date: March 1995
Publication Info: Hydrologic Engineering Center TD-36

Summary: This training document from HEC discusses methods to estimate watershed sediment yield. In addition, a review of procedures for estimating inflowing sediment load and gradation for use in sediment transport model (HEC-6) is also presented. The focus is on development of data for HEC-6. A detailed HEC-6 application example is provided that covers calibration and performance testing approach outlines in HEC’s Training Document No. 13 (TD-13), selection of transport function, and input file setup.

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128 *Title:* **Alluvial Fans in California**

Identification, Evaluation, and Classification

Author: U.S. Army Corps of Engineers

Publication Date: May 2000

Publication Info: U.S. Army Corps of Engineers, Sacramento District

Summary: This study's purpose was to develop a standardized criteria and a step-by-step procedure for identifying and classifying alluvial fans. The report summarizes the current information regarding alluvial fans, proposed a standard definition and base classification system to be used in identifying and classifying alluvial fans throughout California, and makes recommendations regarding land use planning, management, and regulation of alluvial fan areas. Alluvial fans can be separated into four types: 1) inactive fans with no flooding; 2) inactive fans with flooding; 3) active fans with flooding and no development; and 4) active fans with flooding and development. Appendix D contains examples of alluvial fan assessment studies for San Diego, Kern, and Butte Counties.

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129 *Title:* **Hydrologic Modeling System HEC-HMS, Technical Reference Manual**

Author: U.S. Army Corps of Engineers

Publication Date: March 2000

Publication Info: Hydrologic Engineering Center CPD-74B

Summary: This technical reference manual describes the mathematical models that are included as part of the HEC-HMS computer program. In addition, the manual provides information and guidance regarding how and when to use the models and how to estimate a model’s parameters.

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130 *Title:* **Hydrologic Modeling System HEC-HMS, Applications Guide**

Author: U.S. Army Corps of Engineers

Publication Date: December 2002

Publication Info: Hydrologic Engineering Center CPD-74C

Summary: The document illustrates application of program HEC-HMS to typical studies of those undertaken by Corps’ offices, including (1) urban flooding studies, (2) flood-frequency studies, (3) flood-loss reduction studies; (4) flood-warning system planning studies, (5) reservoir design studies, and (6) environmental studies. For each study category, this document identifies common objectives of the study and the authority under which the study would be undertaken. It then identifies the hydrologic engineering information that is required for decision making and the methods that are available in HEC-HMS for developing the information. The manual illustrates how the methods could be configured, including how boundary conditions would be selected and configured.

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131 *Title:* **Hydrologic Modeling System HEC-HMS, User's Manual, Version 3.0.0**

Author: U.S. Army Corps of Engineers

Publication Date: December 2005

Publication Info: Hydrologic Engineering Center CPD-74A

Summary: The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It supersedes HEC-1 and provides a similar variety of options but represents a significant advancement in terms of both computer science and hydrologic engineering. In addition to unit hydrograph and hydrologic routing options, capabilities include a linear quasi-distributed runoff transform (ModClark) for use with gridded precipitations, continuous simulation with either a single-layer or more complex five-layer soil moisture method, and a versatile parameter estimation option. The program features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface allows the user seamless movement between the different parts of the program.

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132 *Title:* **The National Flood Frequency Program-Methods for Estimating Flood Magnitude and Frequency in Rural Areas in Arizona**

Author: USGS

Publication Date: January 1999

Publication Info: Fact Sheet 111-98

Summary: The southwestern United States is divided into 16 hydrologic flood regions, of which 7 include portions of Arizona. These regions were delineated on the basis of regional flood sources (snowmelt, summer thunderstorms, or cyclonic rainfall), elevation, and analysis of flood yields and residuals of preliminary regional flood-frequency relations. Within Arizona, sites greater in elevation than 7,500 feet above sea level (NGVD of 1929) are considered to be in region 1. Sites located at elevations of 7,500 feet or less may belong to regions 8, 10, 11, 12, 13, or 14 on the basis of geographic location. WSP 2433 developed regression equations for estimating peak discharges that have recurrence intervals that range from 2 to 100 years for ungaged, unregulated rural streams. The NFF Program provides estimates of the 500-year discharge on the basis of extrapolation. Although some sites with drainages greater than 200 square miles were used to develop the equations, applications are best limited to 200 square miles or less. The variables used in the regression equations are the drainage area, the mean annual precipitation, the mean basin elevation, and the mean annual evaporation.

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133 *Title:* **The National Flood Frequency Program-Methods for Estimating Flood Magnitude and Frequency in Rural Areas in Nevada**

Author: USGS

Publication Date: September 1999

Publication Info: Fact Sheet 123-98

Summary: The southwestern United States is divided into 16 hydrologic flood regions, of which 6 include portions of Nevada. These regions were delineated on the basis of regional flood sources (snowmelt, summer thunderstorms, or cyclonic rainfall), elevation, and analysis of flood yields and residuals of preliminary regional flood-frequency relations. Within Nevada, sites greater than a threshold that varies with latitude are considered to be in region 1. Sites located at or below the threshold may belong to regions 2, 3, 5, 6, or 10 on the basis of geographic location. WSP 2433 developed regression equations for estimating peak discharges that have recurrence intervals that range from 2 to 100 years for ungaged, unregulated rural streams. The NFF Program provides estimates of the 500-year discharge on the basis of extrapolation. Although some sites with drainages greater than 200 square miles were used to develop the equations, applications are best limited to 200 square miles or less. The variables used in the regression equations are the drainage area, the mean annual precipitation, the mean basin elevation, and the latitude.

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134 *Title:* **The National Flood Frequency Program-Methods for Estimating Flood Magnitude and Frequency in Rural Areas in New Mexico, 2000**

Author: USGS

Publication Date: October 2000

Publication Info: Fact Sheet 055-00

Summary: New Mexico is divided into eight hydrologic regions on the basis of physiography, elevation, and precipitation. WRI 96-4112 developed regression equations for estimating peak discharges in cubic feet per second that have recurrence intervals that range from 2 to 500 years for ungaged, unregulated, rural streams in each of these regions. A ninth set of equations were developed for small watersheds that drain less than 10 square miles and that are less than 7,500 feet in mean basin elevation. The variables used in the regression equations are: drainage area, average channel elevation, mean basin elevation, maximum precipitation intensity for the 24-hour 10-year storm, and maximum precipitation intensity for the 24-hour 25-year storm. This report is a summary of WRI 96-4112.

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135 *Title:* **Sedimentation Engineering**

ASCE Manuals and Reports on Engineering Practice No. 54

Author: Vanoni, V.A.

Publication Date: 1977

Publication Info: Reston, VA: ASCE

Summary: This book has a summary of many sediment yield techniques including in-stream sampling, mathematical models, regression equations, and sediment rating curves.

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136 *Title:* **Flood-Flow Frequency Model Selection in Southwestern United States**

Author: Vogel, R.M., Thomas, W.O. Jr., McMahon, T.A.

Publication Date: May/June 1993

Publication Info: Journal of Water Resources Planning and Management, Vol. 119, No. 3, pp. 353-366

Summary: Uniform flood frequency guidelines in the US recommend the use of the log-Pearson type III (LP3) distribution in flood frequency investigations. Many investigators have suggested alternative models such as the generalized extreme value (GEV) distribution as an improvement over the LP3 distribution. Using flood-flow data at 383 sites in the southwestern US, we explore the suitability of various flood frequency models using L-moment diagrams. We also repeat the experiment performed in the original WRC report, which led to the LP3 mandate. All our evaluations consistently reveal that the LP3, GEV, and the two- and three-parameter lognormal models provide a good approximation to flood-flow data in this region. Other models such as the normal, Pearson, and Gumbel distributions are shown to perform poorly.

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137 *Title:* **Design Flood Determination: Time for an upgrade?**

Bridging the Gap

Author: Voight, R.L., Jr.

Publication Date: 2001

Publication Info: ASCE Conf. Proceedings

Summary: Design flood determination is most often based upon one of two methodologies. When the information is available the design flood is based upon flood frequency analyses of historic records. In many other instances the design flood is based upon the methodologies presented in the United States Soil Conservation Service (SCS) Handbook of Hydrology. Numerous examples of floods exceeding the anticipated magnitude or design frequency exist throughout the United States. This paper will summarize selected floods, provide an example where a standard design analysis does not solve a frequent flooding problem, and present four often overlooked reasons for flood magnitudes greater than anticipated. Flood frequency analyses based upon historic records are typically developed using the largest flood of record for each year and do not incorporate additional floods during that year. By default, this has the direct implication of reducing the magnitude of a flood for a given return frequency. The level of impact will be site specific and will relate to the site's climatic variability. Design floods based upon the historic SCS methodologies normally use antecedent soil moisture condition II (AMC II). Information presented will include the likelihood of an event occurring under the wet soil conditions of AMC III and the resultant effect on flooding magnitudes and frequency.

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138 *Title:* **Magnitude and Frequency of Floods in California**

Author: Waananen, A.O., and Crippen, J.R.

Publication Date: June 1977

Publication Info: USGS WRI Report 77-21

Summary: The magnitude and frequency of floods from gaged and ungaged drainage areas in California, for any recurrence interval from 2 to 100 years, can be estimated by use of the method presented. Equations relating flood magnitudes of selected frequency to basin characteristics such as drainage area, precipitation, and altitude were developed for six regions in the State. Nomographs are included for solution of the equations. The regression equations were developed for streams that have natural flow or flows not substantially affected by storage.

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139 *Title:* **Relative Accuracy of Log Pearson III Procedures**

Author: Wallis, J.R., and Wood, E.F.

Publication Date: July 1985

Publication Info: Journal of Hydraulic Engineering, Vol. 111, No. 7, pp. 1043-1056

Summary: The US Water Resources Council has suggested that the log-Pearson III distribution, fitted by the method of moments, should be used in flood frequency analyses. A Monte Carlo simulation of the WRC procedures shows that the flood quantile estimates obtainable by these procedures are poorer than those obtainable by using an index flood type approach with either a generalized extreme value distribution or a Wakeby distribution fitted by probability weighted moments. It is suggested that the justification for using WRC Bulletin 17B guidelines is in need of re-evaluation.

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140 *Title:* **Techniques for Estimating Flood-Flow Frequency for Unregulated Streams in New Mexico**

Author: Waltemeyer, S.D.

Publication Date: 1986

Publication Info: USGS WRI Report 86-4104

Summary: Equations for estimating flood discharges for exceedance probabilities of 0.50, 0.20, 0.10, 0.04, 0.02, and 0.01 at ungaged sites were developed and updated from streamflow gaging station data through 1982. The 1984 data from selected stations in the southwestern part of the State also were used because of the high discharges that occurred during that year. The State was divided into eight physiographic regions and equations were developed for each region. The logarithms of annual flood peaks for the respective exceedance probabilities were related to logarithms of basin and climatic characteristics. New techniques for weighting independent estimates of flood discharges at gaging stations by each estimate's variance are presented.

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141 *Title:* **Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico**

Author: Waltemeyer, S.D.

Publication Date: 1996

Publication Info: USGS WRI Report 96-4112

Summary: Equations for estimating the magnitude of peak discharges for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years were updated for New Mexico. The equations represent flood response for eight distinct physiographic regions of New Mexico. Additionally, a regional equation was developed for basins less than 10 square miles and below 7,500 feet in mean basin elevation. Flood-frequency relations were updated for 201 gaging stations on unregulated streams in New Mexico and the bordering areas of adjacent States. The analysis described in this report used data collected through 1993. A low-discharge threshold was applied to frequency analysis of 140 gaging stations. Inclusion of these low peak flows affects the fitting of the lower tail and the upper tail of the distribution. Peak discharges can be estimated at an ungaged site on a stream that has a gaging station upstream or downstream. These estimates are derived using the drainage-area ratio and the drainage-area exponent from the regional regression equation of the respective region. Flood-frequency estimates for 201 gaged sites were weighted by estimates from the regional regression equation. The observed, predicted, and weighted flood-frequency data were computed for each gaging station. A maximum observed peak discharge as related to drainage area was determined for eight physiographic regions in New Mexico. Peak-discharge data collected at 201 gaging stations were used to develop a maximum peak-discharge relation as an alternative method of estimating the peak discharge of an extreme event.

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142 *Title:* **Analysis of the Magnitude and Frequency of the 4-Day Annual Low Flow and Regression Equations for Estimating the 4-Day, 3-Year Low Flow Frequency at Ungaged Sites on Unregulated Streams in New Mexico**

Author: Waltemeyer, S.D.

Publication Date: 2002

Publication Info: USGS WRI Report 01-4271

Summary: Two regression equations were developed for estimating the 4-day, 3-year (4Q3) low-flow frequency at ungaged sites on unregulated streams in New Mexico. The first, a statewide equation for estimating the 4Q3 low-flow frequency from drainage area and average basin mean winter precipitation, was developed from the data for 50 streamflow-gaging stations that had non-zero 4Q3 low-flow frequency. The 4Q3 low-flow frequency for the 50 gaging stations ranged from 0.08 to 18.7 cfs. The second, an equation for estimating the 4Q3 low-flow frequency in mountainous regions from drainage area, average basin mean winter precipitation, and average basin slope, was developed from the data for 40 gaging stations located above 7,500 feet in elevation.

143 *Title:* **Regional Flood Frequency Equations for Antelope Valley in Kern County, California**
Hydraulics/Hydrology of Arid Lands (H2AL)

Author: Wang, W.C., Dawdy, D.R.

Publication Date: 1990

Publication Info: ASCE Conf. Proceedings

Summary: This paper evaluates the validity of the USGS regional flood frequency equations in support of development of appropriate hydrology for use in the Antelope Valley, California. The paper is a good reference that investigates the applicability of the USGS regression equations, and the observations that lead to rejection of such equations in order to develop a new set of regional equations using local flood data. The USGS regional equations were identified to be based heavily on the flood data of the Mojave Desert and the Imperial Valley, where streams are characterized by large flood peaks. The paper shows that the USGS equations generally over-estimate flood peaks in the Antelope Valley. The new set of regression equations developed for local use gives a greater confidence limit in peak discharge when compared to that from the USGS regional regression equations. To check the applicability of the USGS equations to the streams in the Antelope Valley, flood data for the streams in the region were plotted against drainage area. For a given drainage area, a stream in the Mojave Desert or Imperial Valley was seen to have a greater flood peak than a stream in the Antelope Valley, while a stream in the Owens Valley was seen to have the lowest peak. Except for the 2-year flood event, the distinctions among the three sub-regions were apparent. The reasonable explanation for this tendency, as stated in the paper, is that the frequent flood events (e.g., the 2-year flood) are predominantly caused by winter frontal-type storms that typically last for several days. These storms cover a broad geographical area, and tend to be characterized by a rather uniform functional relationship between flood peak and drainage area over the entire region. The infrequent flood events are result of localized summer thunderstorm activity affected by climatological characteristics of the individual sub-regions. Hence the functional relationship between flood peak and drainage area varies with the sub-region.

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144 *Title:* **Climatic Variability and Flood Frequency of the Santa Cruz River, Pima County, Arizona**

Author: Webb, R.H., Betancourt, J.L.

Publication Date: 1992

Publication Info: USGS Water Supply Paper 2379

Summary: Past estimates of the 100-year flood for the Santa Cruz River at Tucson, Arizona, range from 572 to 2,780 cubic meters per second. An apparent increase in flood magnitude during the past two decades raises concern that the annual flood series is non-stationary in time. The apparent increase is accompanied by more annual floods occurring in fall and winter and fewer in summer. Estimation of flood frequency on the Santa Cruz River is complicated because climate affects the magnitude and frequency of storms that cause floods. Mean discharge does not change significantly, but the variance and skew coefficient of the distribution of annual floods change with time. The 100-year flood during El Nino-Southern Oscillation conditions is 1,300 cubic meters per second, more than double the value for other years. Flood frequency based on hydro-climatology was determined by combining populations of floods caused by monsoonal storms, frontal systems, and dissipating tropical cyclones. For 1930-1959, annual flood frequency is dominated by monsoonal floods, and the estimated 100-year flood is 323 cubic meters per second. For 1960-1986, annual flood frequency at recurrence intervals of greater than 10 years is dominated by floods caused by dissipating tropical cyclones, and the estimated 100-year flood is 1,660 cubic meters per second. For design purposes, 1,660 cubic meters per second might be an appropriate value for the 100-year flood at Tucson, assuming that climatic conditions during 1960-1986 are representative of conditions expected in the immediate future.

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145 *Title:* **Sediment Delivery by Ungaged Tributaries of the Colorado River in Grand Canyon**

Author: Webb, R.H., Griffiths, P.G., Melis, T.S., Hartley, D.R.

Publication Date: 2000

Publication Info: USGS Water Resources Investigations 00-4055

Summary: Three techniques were used to estimate annual streamflow sediment yield from ungaged tributaries to the Colorado River: 1) a regression equation relating drainage area to sediment yield for all relevant sediment-yield data from northern Arizona, 2) an empirical relation developed by Renard, and 3) a new procedure that combines regional flood-frequency analysis with sediment rating curves. All three methods are compared against regional data to determine their appropriateness for estimating sediment yield to the Grand Canyon.

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146 *Title:* **Debris Flows from Tributaries of the Colorado River, Grand Canyon National Park, AZ**

Author: Webb, R.H., Pringle, P.T., Rink, G.R.

Publication Date: 1989

Publication Info: USGS Professional Paper 1492

Summary: The purpose of this report is to document the extent of debris flows in the Grand Canyon National Park and the occurrence and magnitude of debris flows in three Colorado River tributaries. The effects of these events on the mainstem-channel morphology are necessary to understand sediment transport and hydraulic controls in the Colorado River. The sediment yield of historic debris flows was estimated using a sediment mass balance technique.

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147 *Title:* **Floods in New Mexico, Magnitude and Frequency**

Author: Wiard, L.A.

Publication Date: 1962

Publication Info: USGS Circular 464

Summary: This report presents a method of determining the magnitude and frequency of floods that can be expected in New Mexico. The discharge of the mean annual flood for various regions in the State is defined. Curves relate mean annual flood and drainage area. Drainage area was the only basin characteristic found to have an appreciable effect on discharge except in two regions where a relation with altitude also is defined. Composite frequency curves relate discharge of the mean annual flood to the discharge of floods having recurrence intervals from 1.1 to 50 years. These relationships are based on records of 5 or more years in length from gaging stations that had flow essentially unregulated.

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148 *Title:* **Process-Based Debris-Flow Prediction Method**

Hydraulics/Hydrology of Arid Lands (H2AL)

Author: Williams, S.R., Lowe, M.

Publication Date: 1990

Publication Info: ASCE Conf. Proceedings

Summary: An alternative to the traditional approaches is presented for debris-flow prediction. Traditional methods have been centered around clear-water hydrologic model methodology. Per these methods, debris flow beyond a canyon mouth is determined by the volume of debris produced from the flood source area and channel conditions. This paper documents the fact that measurement and calculations of sediment production from the flood source areas show that their debris contribution is usually less than 20% of the total and in many cases negligible. Most debris is derived from the channel. However, debris production and accumulation in channels are slow intermittent geologic processes; re-accumulation after an event may take a long time. A recently scoured stream channel cannot contribute the same volume of debris during subsequent events as it did during an initial event. Based on this logic, any debris flow which scours a perennial stream channel represents a Probable Maximum Flood (for debris volume) rather than something rated under traditional return period criteria. Therefore, authors sought to find a relationship to quantify volume of debris contributed by a stream per linear distance, which may represent a debris volume (PMF) for a particular Canyon. Their findings are supported by historical conditions, stream-channel conditions, watershed mitigation practices in relation to vegetation cover, frequency of wild fires, and landslides.

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149 *Title:* **San Bernardino County Hydrology Manual**
Author: Williamson and Schmid
Publication Date: August 1986
Publication Info: San Bernardino Flood Control District

Summary: The Manual provides the computational techniques and criteria for the estimation of runoff, discharges, and volumes for use in hydrology study submittals to the County of San Bernardino. The two primary methods used to determine design discharges are the Rational method (for areas less than a square mile) and the Synthetic Unit Hydrograph method (for watersheds in excess of this limit). Precipitation data is based on NOAA Atlas 2. Example problems are included to clarify the methods.

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150 *Title:* **Debris Flows and Hyperconcentrated Streamflows**
Water Forum '86
Author: Wisczorek, G.F.
Publication Date: 1986
Publication Info: ASCE Conf. Proceedings

Summary: Potential for real-time debris flow hazard warning is assessed through examination of debris-flow and hyperconcentrated streamflow events in the western United States. The case studies discussed illustrate some common physiographic settings and climatic triggering mechanisms for flows in mountainous regions of the West. To identify areas subject to debris flow and to plan and design for their occurrence it is necessary to (1) determine where they are likely to occur, (2) determine when they are likely to occur, and (3) determine where and how far they are likely to travel. Methods for mapping debris-flow susceptibility developed and evaluated in the San Francisco Bay area and in the Wasatch Range of Utah are mentioned. The applicability of these locally successful methods remains unknown. The difficulty of properly estimating volume and flow rate of potential debris flows or hyperconcentrated streamflows seriously affect accuracy of evaluating routing or run out. However, recognition of debris-flow triggering events and analysis to identify thresholds critical for the triggering of debris flows provide the possibility of issuing hazard warnings. The paper seeks to find the tradeoff between available mapping/mathematical methods and geophysical conditions that can trigger these potentially hazardous conditions in the arid west.

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151 *Title:* **Sediment Transport Capacity in Rivers**
Author: Yang S O

Author: Yang, S.Q.

Publication Date: July 2004

Publication Info: Journal of Hydraulic Research, Vol. 42, No. 3, pp. 131-138

Summary: This paper investigates the sediment transport capacity in rivers. The correlation between total sediment discharge and various hydraulic parameters is examined using 1,593 records in the database compiled by Brownlie.

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152 *Title:* **Unit Hydrograph Derivation for Ungauged Watersheds by Stream-Order Law**

Author: Yen, B.C., Lee, K.T.

Publication Date: January 1997

Publication Info: Journal of Hydrologic Engineering, Vol. 2, No. 1, pp. 1-9

Summary: The recently proposed geomorphologic instantaneous unit hydrograph (GIUH) method is perhaps the most promising development in determining the unit hydrograph (UH) for ungaged or inadequately gaged watersheds without the need of observed runoff and rainfall data. In this method, the geomorphic ratios of the Horton-Strahler stream ordering laws are incorporated in the GIUH model for UH generation. Testing of the model on two hilly watersheds in the eastern US and two relatively flat sloped watersheds in Illinois are presented.

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153 *Title:* **Magnitude and Frequency of the Floods in the United States, Part II Pacific Slope Basins in California**

Volume I: Coastal Basins South of the Klamath River Basin & Central Valley Drainage from the West

Author: Young, L. E., Cruff, R. W.

Publication Date: 1967

Publication Info: USGS Water Supply Paper 1685

Summary: This report presents a method for determining the probable magnitude of floods for any recurrence interval between 1.2 and 50 years for any stream, gaged or ungaged, in the area studied. The area covered by this report includes those streams in California that drain into the Pacific Ocean between Mexico on the south and the Klamath River basin on the north, plus those streams that drain from the west into the Central Valley south of the Clear Creek basin. The area has been divided into two regions of differing flood-frequency characteristics. The hydrologic basin characteristics having the most significant effect on the flood magnitude were drainage area, mean annual precipitation, and altitude. These were used as independent variables to derive equations for determining flood magnitudes with recurrence intervals of 1.2, 2.33, 5, 10, 25, and 50 years. From the equations, flood magnitude-frequency relations can be constructed. The procedure for computing flood magnitude is not applicable at sites where the drainage area is less than 10 square miles or where the usable storage exceeds 4.5 million cubic feet (103 acre-feet) per square mile.

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154 *Title:* **Magnitude and Frequency of the Floods in the United States, Part II Pacific Slope Basins in California**

Volume II: Klamath & Smith River Basins and Central Valley Drainage from the East

Author: Young, L. E., Cruff, R. W.

Publication Date: 1967

Publication Info: USGS Water Supply Paper 1686

Summary: This report presents a method for determining the probable magnitude of annual maximum flood flows for any recurrence interval between 1.2 and 50 years for any stream, gaged or ungaged, in the area studied. The area covered by this report includes the Klamath and Smith River basins and the small streams between them that drain into the Pacific Ocean, plus all streams draining into the Central Valley from the east and those draining into the Central Valley from the west, north of the Cottonwood Creek basin. The area has been divided into four regions of differing flood-frequency characteristics. The flood-frequency relation is undefined in one of these regions (the flat Central Valley) because of the lack of records for unregulated streams within its boundaries. The hydrologic basin characteristics having the most significant effect on the flood magnitude were drainage area, mean annual precipitation, slope, and altitude. These were used as independent variables to derive equations for determining flood magnitudes for recurrence intervals of 1.2, 2.33, 5, 10, 25, and 50 years. From these equations, flood magnitude-frequency relations can be constructed. The procedure for computing flood magnitude is not applicable at sites where the drainage area is less than 10 square miles or where the usable storage exceeds 4.5 million cubic feet (103 acre-feet) per square mile.

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155 *Title:* **Phoenix Flood Hydrology for Price Expressway**

Hydraulics/Hydrology of Arid Lands (H2AL)

Author: Zovne, J.J., Miller, L.S.

Publication Date: 1990

Publication Info: ASCE Conf. Proceedings

Summary: The paper summarizes HDR Engineering's stormwater modeling approach using U.S. Army Corps of Engineers Flood Hydrograph Package, HEC-1 for a complex 58 square miles drainage basin intercepted by the Price Expressway and Santan Freeway in suburban Phoenix. The project was completed for the Arizona Department of Transportation. The roadways offered unique stormwater management challenges as they were constructed as depressed roadway sections through rapidly growing suburban communities. Key assumptions in HDR's modeling approach involved the initial abstractions and loss rates, and the manner in which the very large number of individual subbasins were linked and routed. The initial abstractions (IA), and loss rate (LR) options in the Soil Conservation Service (SCS) method were used to account for detention in the developed and irrigated areas in lieu of modeling every on-site detention basin in the area. In agricultural areas where most fields have berms to retain and conserve irrigation water, a separate study was done to determine the required increase in the IA to account for the storage effect. The HEC-1 models were used to calculate total stormwater volumes and peak flows for design of a multiple basin and pump station stormwater management facility.

Interviews with Agency Personnel

Agency	Caltrans District 02
Contact	Steve Thorne
Position	Hydrologic Engineer
Telephone	
Email	
Comments	- Use regional regression, basin comparisons - Rational Method for small basins - Although they have desert regions, they don't have any "special" ways of estimating Q's for those areas.

Agency	Caltrans District 06
Contact	Tom Fisher
Position	Hydrologic Engineer
Telephone	
Email	
Comments	- Referred us to Andrew Brandt in District 9

Agency	Caltrans District 07
Contact	J. Paul Thacker
Position	Chief, Hydraulics
Telephone	2138977546
Email	
Comments	- Phone interview on 2/27/06 - 3 regional heads -- Ventura County, N. LA County, S. LA County - Referred us to Ralph Sasaki, oldest hydraulic engineer in District

Agency	Caltrans District 08
Contact	John Rogers
Position	Office Chief, Hydraulics
Telephone	9093834555
Email	
Comments	- Phone interview on 2/28/06 - Use HDM: regional equations or Rational Method - Confer with San Bernardino Flood Control District - CivilDesign is used a lot - No one in group uses WMS - New freeways are rarely built - Mostly urbanized hydrology problems, rather than desert hydrology - Bulking factor is used on a case-by-case basis

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Agency	Caltrans District 09
Contact	Andrew Brandt
Position	District Hydrologist
Telephone	7608728036
Email	
Comments	- Phone interview on 2/27/06 - For larger basins, regional regression equations from USGS Water Supply Paper 1543-A are used; more accurate for Eastern Sierra than other regional equations. - Gage data is available from LA Dept. of Water and Power. - Bulking factor is not typically used. Previous hydrologist (Truman Denio) may have used bulking factor. - Rational Method and Excel spreadsheet for tc used for smaller basins - WMS used to delineate watersheds, but don't use a lot within WMS anymore. - Index flood-frequency analysis is used.

Agency	Caltrans District 11
Contact	Karen Jewel
Position	
Telephone	6196883391
Email	
Comments	- Phone interview on 2/28/06 - Use Rational Method for smaller areas - One rain gage in desert -- out in El Centro; use IDF program - Old studies used regional equations provided in HDM. - Don't do too many hydrologic studies in the desert areas. - Just started looking at NOAA Atlas 14; haven't used it yet. - SCS method used for larger watersheds, detention-type work - Everything drains to Imperial Irrigation District facilities; IID limits Caltrans connections to 12" drains; plus limited number of connections Therefore, need to analyze as detention. - IID has no good records in terms of rain data, or ag flow vs. storm flow; no info avail. from county. - Don't use San Diego County Hydrology Manual for calcs; it has been shown to produce much higher values than the previous manual. - Bulking factor: no standard method; sometimes look at Riverside County methodology

Agency	City of Barstow
Contact	Michael Stewart, P.E.
Position	City Engineer
Telephone	7602555156
Email	mstewart@barstowca.org
Comments	- City uses San Bernardino County Hydrology Manual - John Rogers is local Caltrans District 8 contact - Mr. Stewart has been in Barstow for 5 years; knows a man who has been in Barstow since 1946 and is a wealth of information. - I-15 near rest stop; lowering of streambed may be intentional instead of due to storms; Army base nearby and tanks go under the bridge. - Armory Wash is a natural bottom channel; now 6 to 10 feet deeper; debris is next to freeway; enters Caltrans concrete-lined portion.

Agency	San Bernardino Flood Control District
Contact	Michael Fox, P.E.
Position	Chief, Water Resources Division
Telephone	9093878213
Email	mfox@dpw.sbcounty.gov
Comments	- Ted Hromadka will be updating Hydrology Manual now that NOAA Atlas 14 has been completed. - Maricopa County, AZ, and Clark County, NV, had concerns with NOAA Atlas 14 because a number of rainfall gages with short periods of record were not included even though they had one or more large storm events. - Rational method typically used; HEC-HMS or HEC-1 models not typically submitted, but would consider their use. - Hydrology Manual is not calibrated for desert areas. - For desert vegetation curve numbers, chart is used more than curves. (question of open brush vs. chaparral C values). - Bulking factor: 100% bulking (BF = 2) is used. Increase depth in trapezoidal channel by 50% is equivalent to doubling the Q, hence 100% bulking is used. - NEXRAIN (Dave Curtis) has looked at where gages could be placed to track storms; could come up with a more accurate depth-area reduction (more than current one based on Sierra Madre). - Low loss fraction in Hydrology Manual was devised by Ted Hromadka to allow some runoff in all cases. - Significant flooding event in Barstow caused flooding of I-40; subject of a lawsuit; ask Caltrans District office regarding storm event; NEXRAIN did an animation of the storm - I-15 and Stoddard Wells; high water marks were measured following large storm event; next to solid waste facility - Event in Twentynine Palms 2 or 3 years ago; streamgage data for major storm event; dip crossing; type of storm is extremely rare, plus its location is what matters. Storm cell stalled over south Barstow and dumped rainfall; Kitchen Wash in east Barstow, flood waters jumped Rimrock Road, flooded Walmart parking lot. - Caltrans typically deals with larger watersheds.

Agency	USBR
Contact	Tony Wahl
Position	Hydraulic Engineer
Telephone	3034452155
Email	twahl@do.usbr.gov
Comments	- Tony Wahl found an old USBR publication on sediment yield titled "Analysis of flow duration/sediment rating curve method for computing sediment yield" by Carl Miller (1951). He agreed to make a copy and send it to WEST. - He also mentioned that there was an update to the 1951 report and that he would make a copy of it and send it to WEST.

Agency	USGS
Contact	Dave Anning
Position	Hydrologist
Telephone	9285567139
Email	dwanning@usgs.gov
Comments	- Dave Anning suggested talking to two other USGS staff: Blake Thomas and Chris Smith.

Agency	USGS
Contact	Blake Thomas
Position	Hydrologist
Telephone	5206706671
Email	bthomas@usgs.gov
Comments	- Blake Thomas said that WSP 2433 and WRI 94-4002 were good summaries of hydrology work that the USGS had done in the arid southwest. - He was not aware of any new research being done by the USGS.

APPENDIX B

Geospatial Data for California's Desert Regions

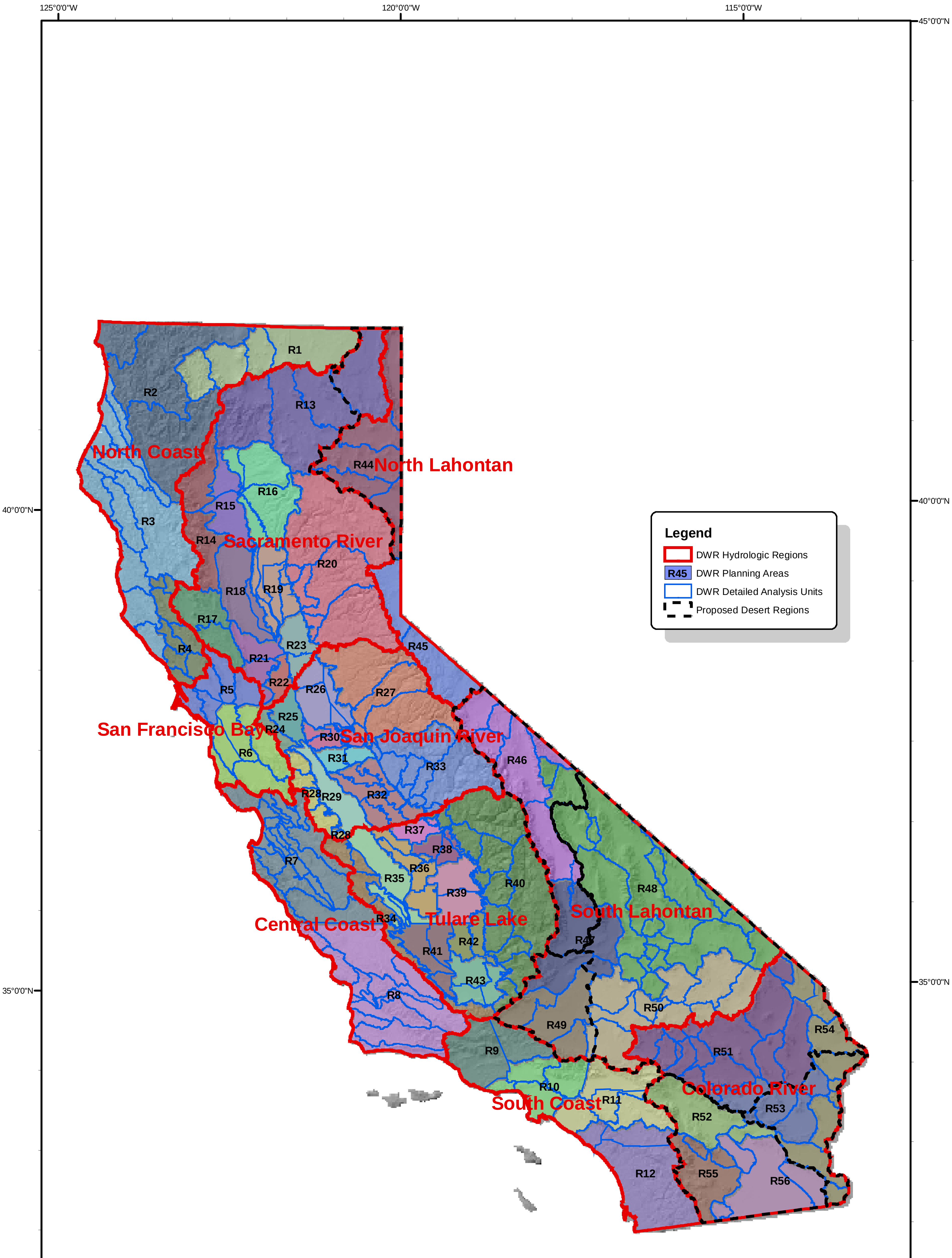

Figure B-1
DWR Hydrologic Regions, Planning Areas, and Detailed Analysis Units

Caltrans Desert Hydrology
May 2007

WEST
CONSULTANTS, INC.

Source: California Department of Water Resources

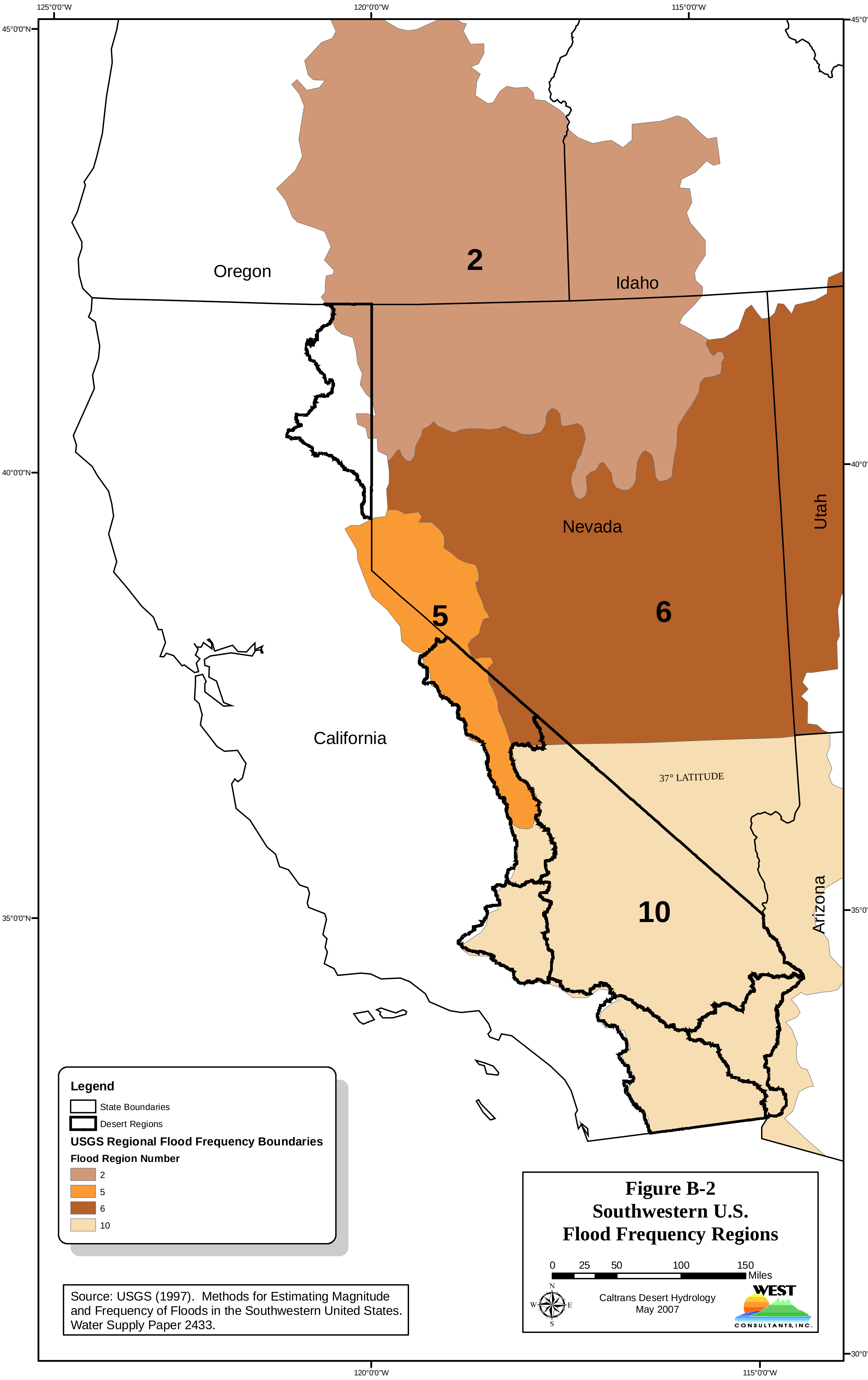

Figure B-2
Southwestern U.S.
Flood Frequency Regions

Caltrans Desert Hydrology
May 2007

Source: USGS (1997). Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States. Water Supply Paper 2433.

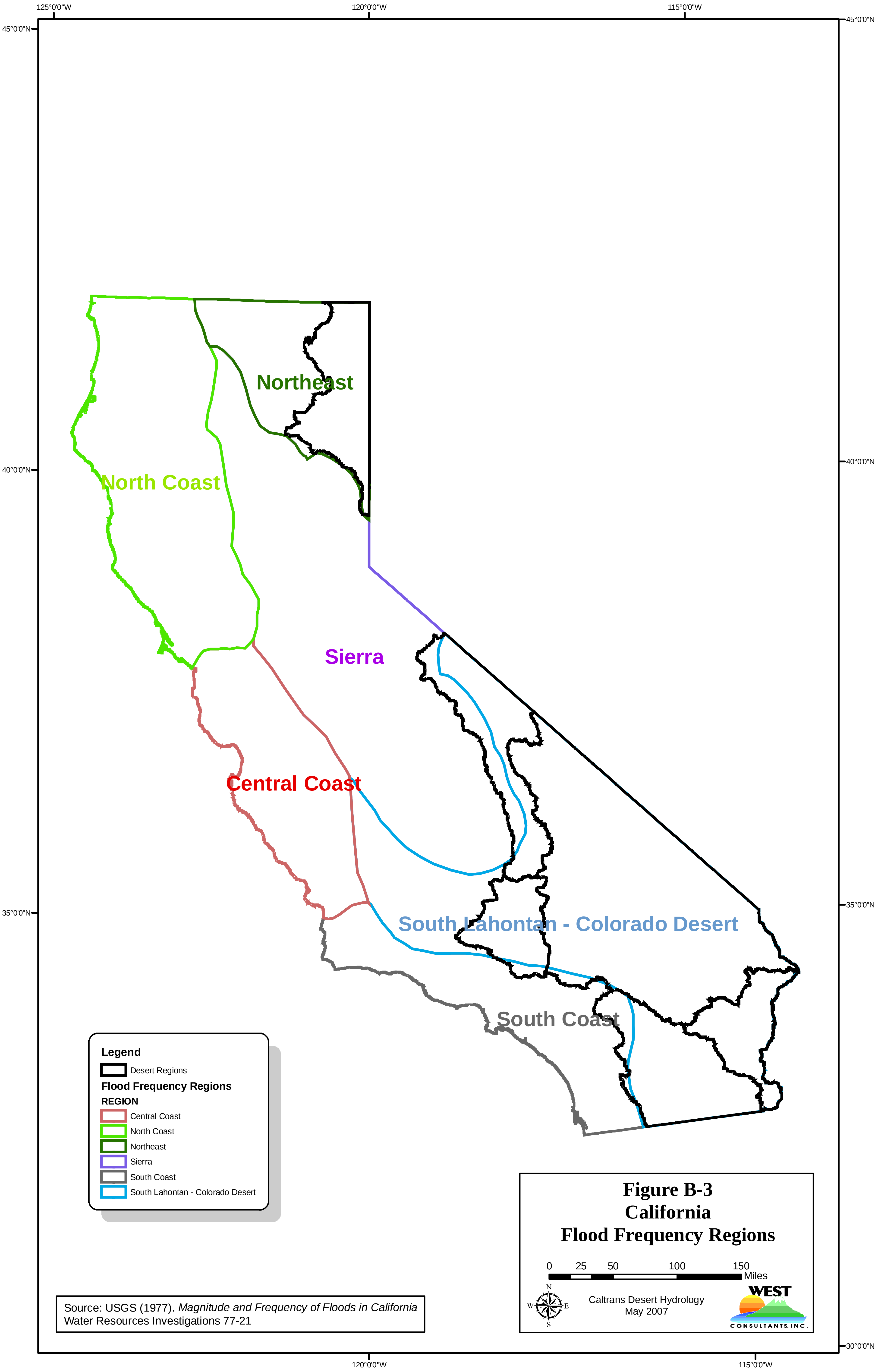

Figure B-3
California
Flood Frequency Regions

Source: USGS (1977). *Magnitude and Frequency of Floods in California* Water Resources Investigations 77-21

Caltrans Desert Hydrology
May 2007

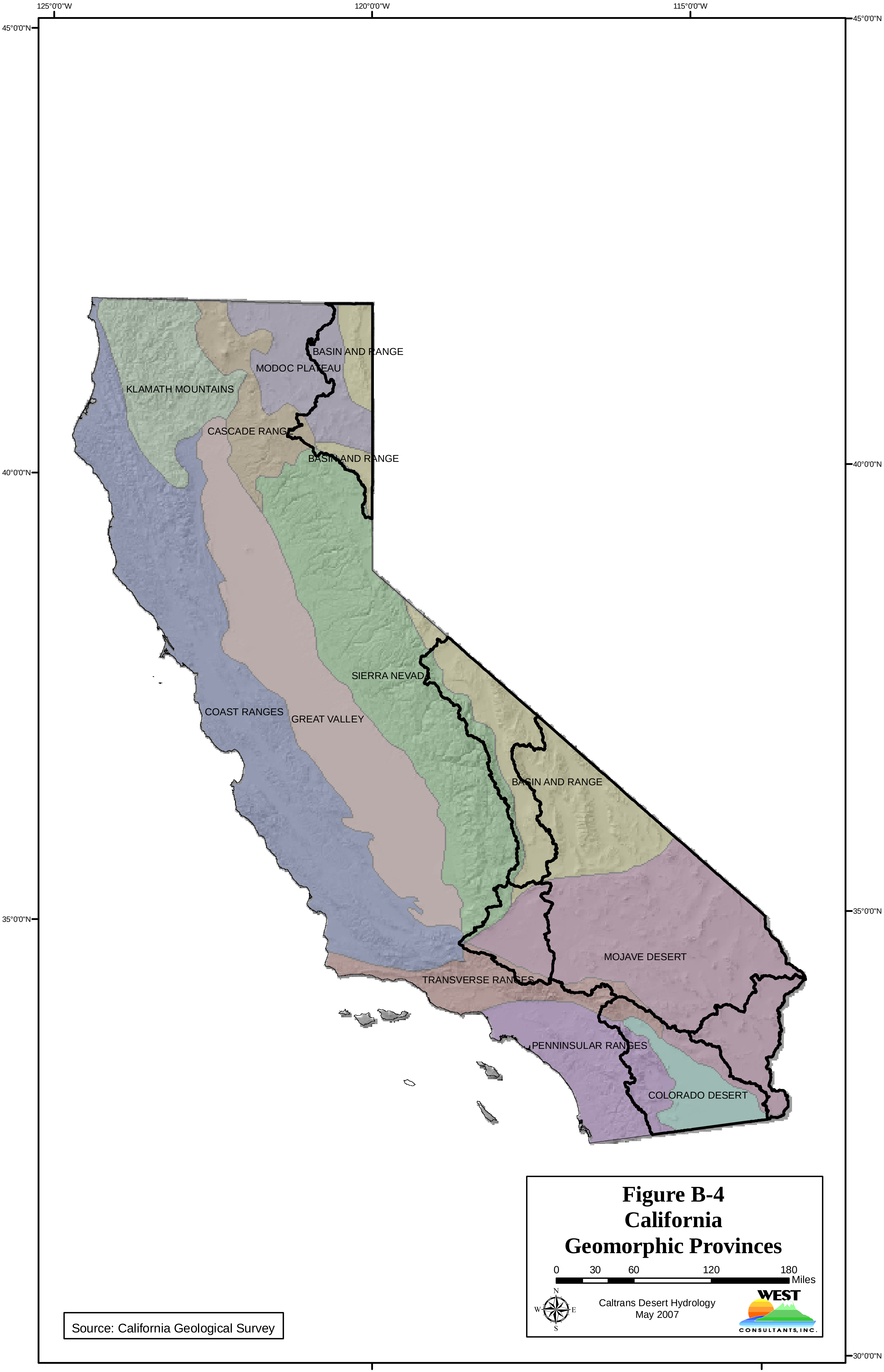

Figure B-4
California
Geomorphic Provinces

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Source: California Geological Survey

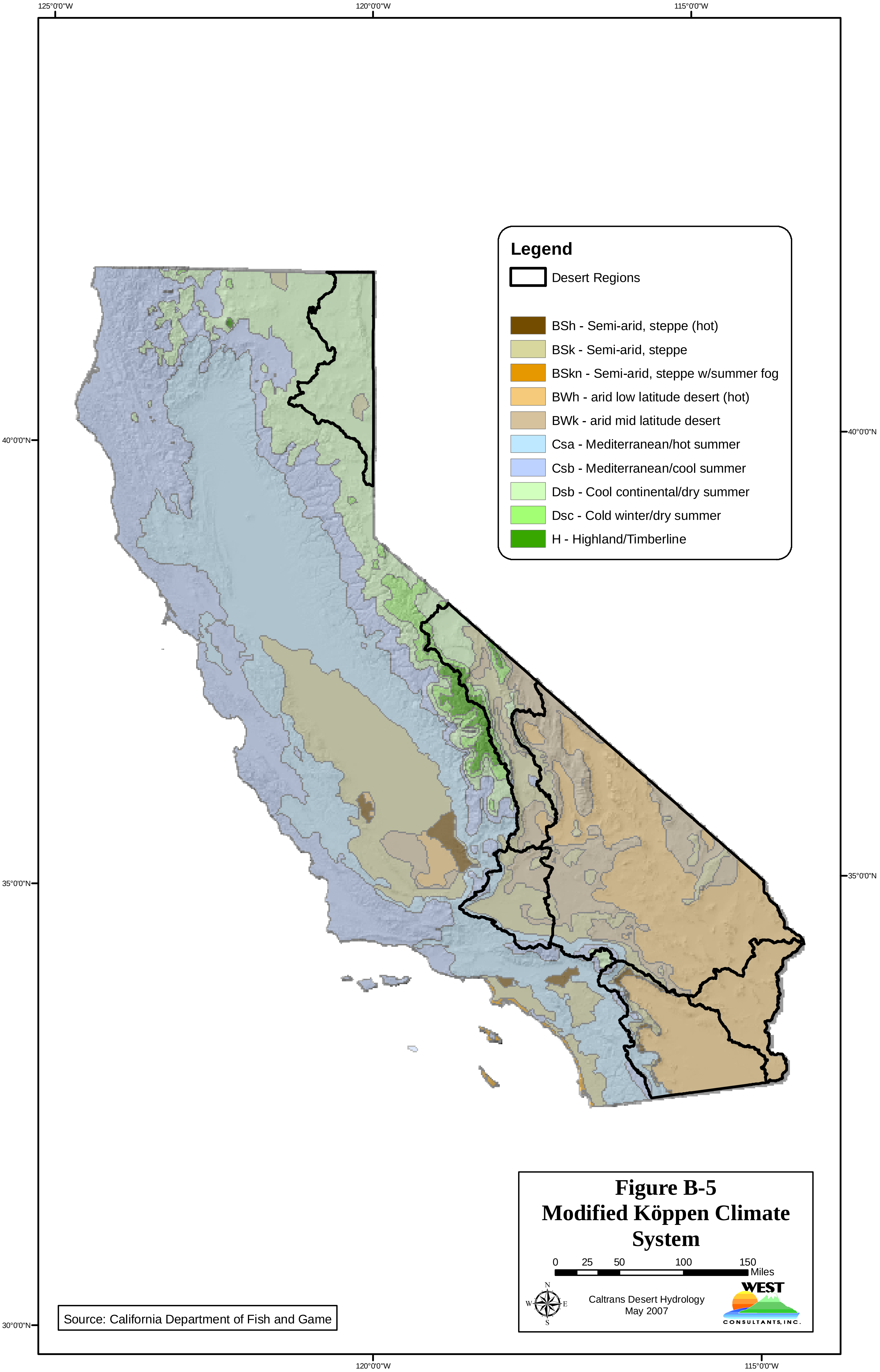

Figure B-5
Modified Köppen Climate System

Source: California Department of Fish and Game

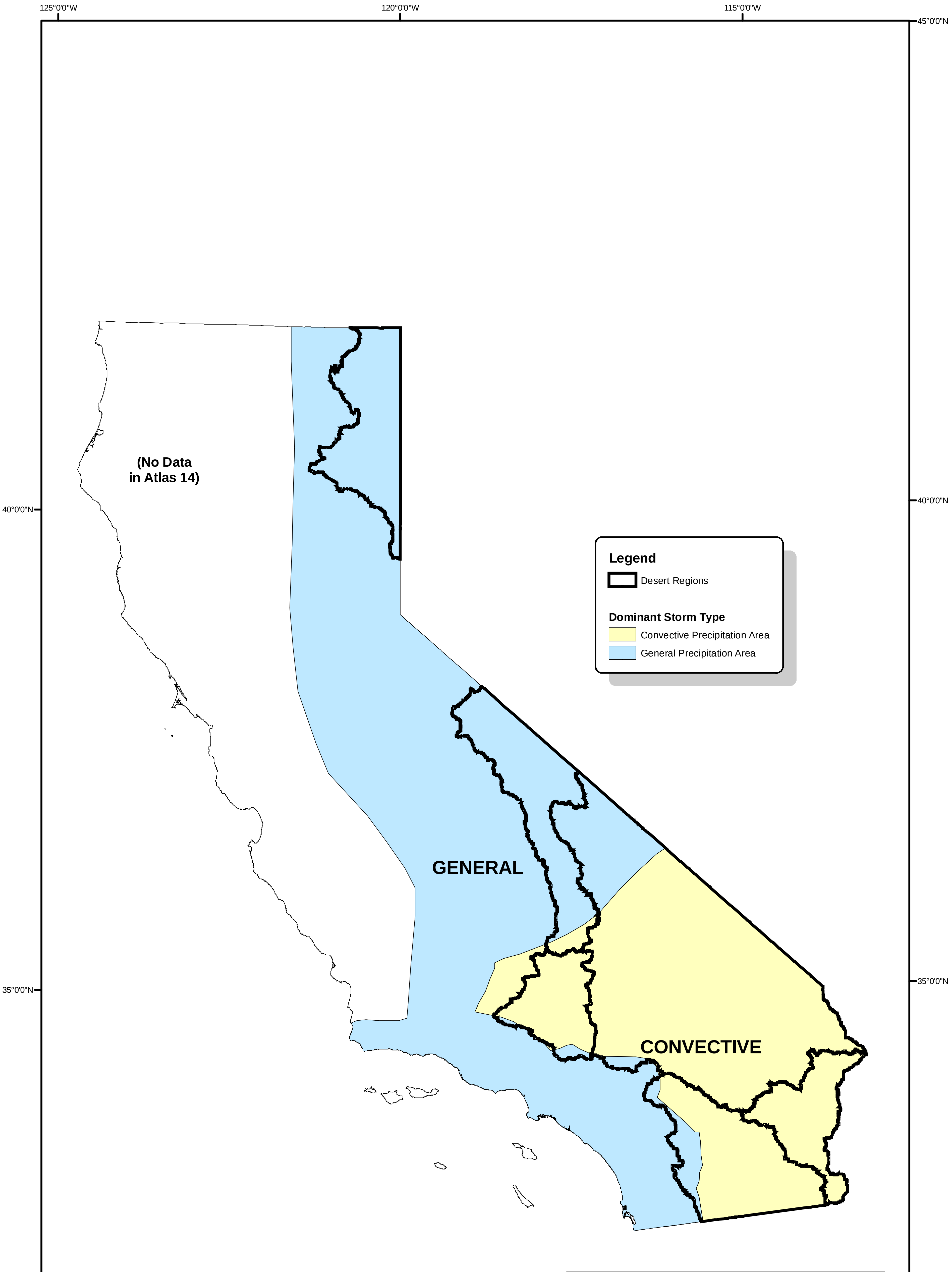

Figure B-6
Precipitation Limits
Convective vs. General

Caltrans Desert Hydrology
May 2007

WEST CONSULTANTS, INC.

Source: NOAA (2004). *Precipitation-Frequency Atlas of the United States*
NOAA Atlas 14, Volume 1: Semiarid Southwest

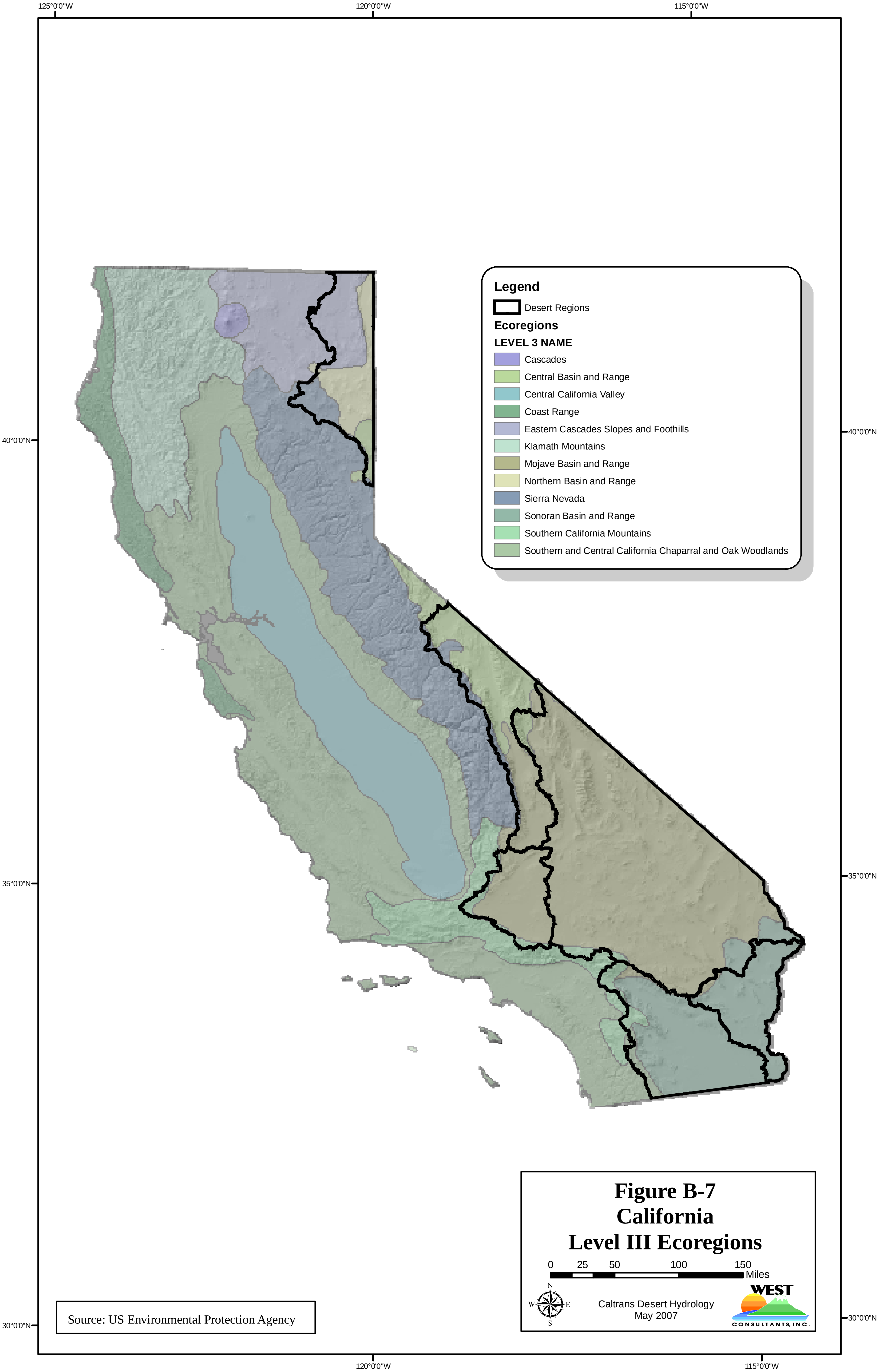

Figure B-7
California
Level III Ecoregions

Source: US Environmental Protection Agency

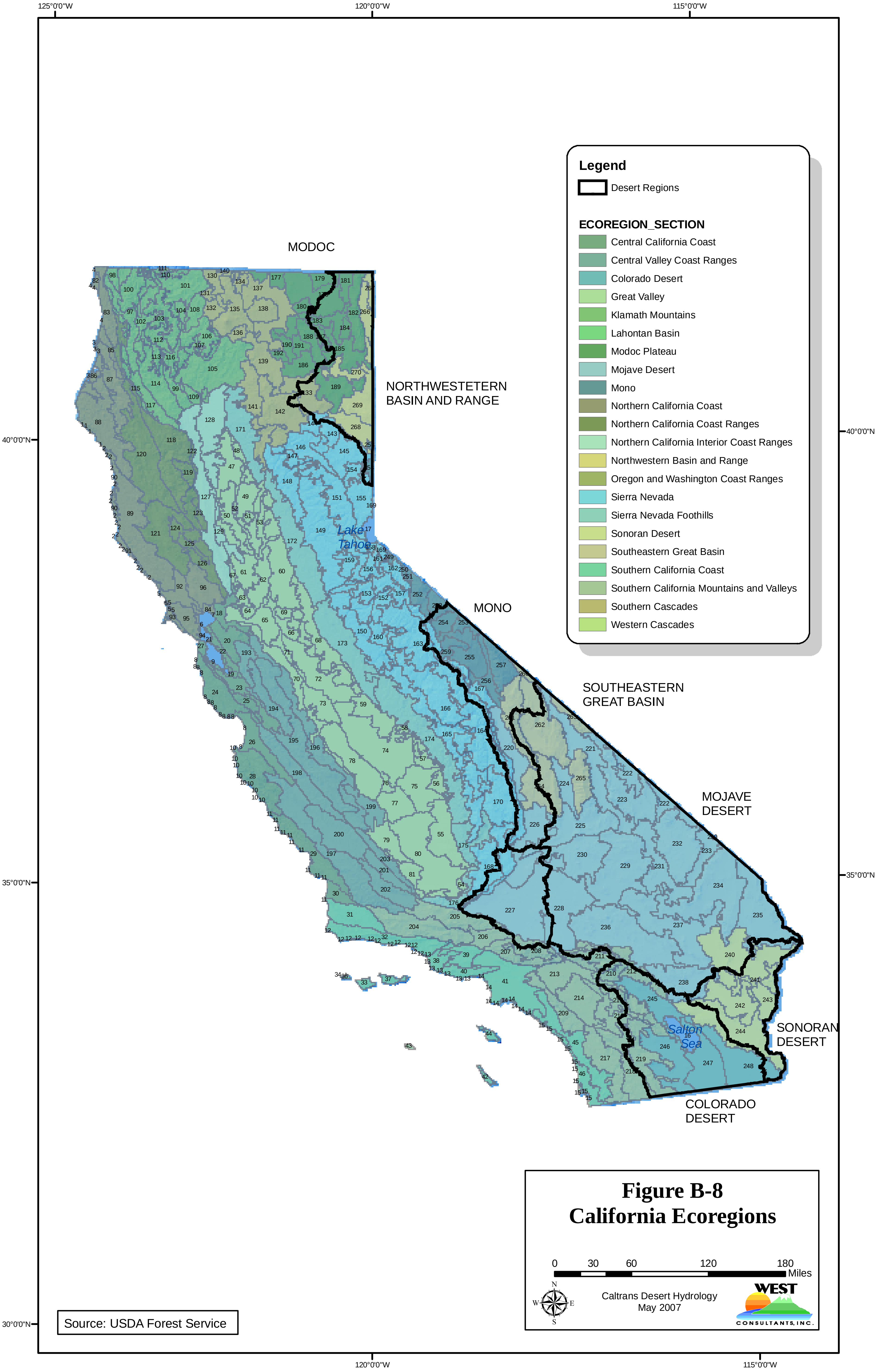

Figure B-8
California Ecoregions

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WEST CONSULTANTS, INC.

Source: USDA Forest Service

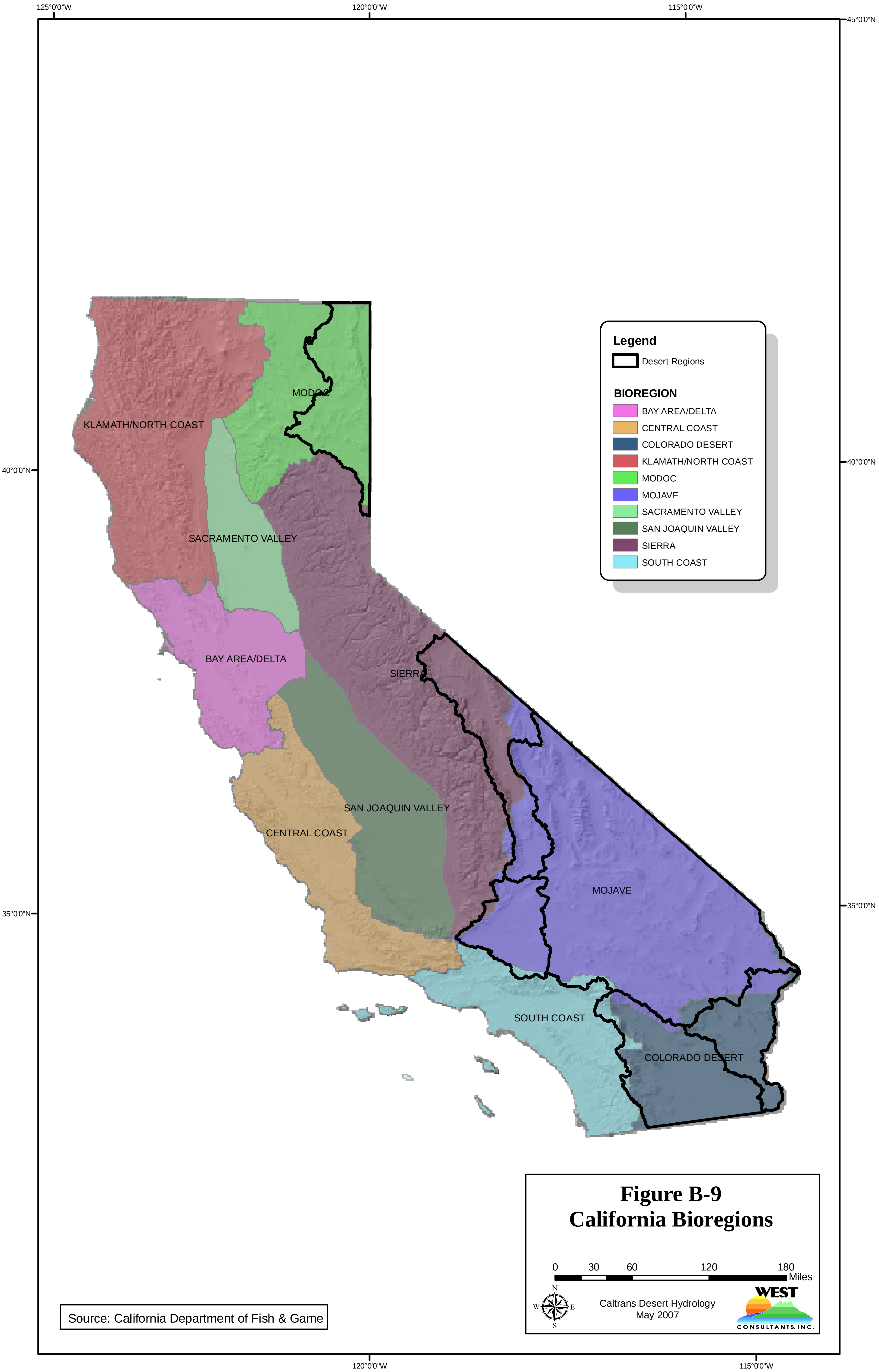

Figure B-9
California Bioregions

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May 2007

Source: California Department of Fish & Game

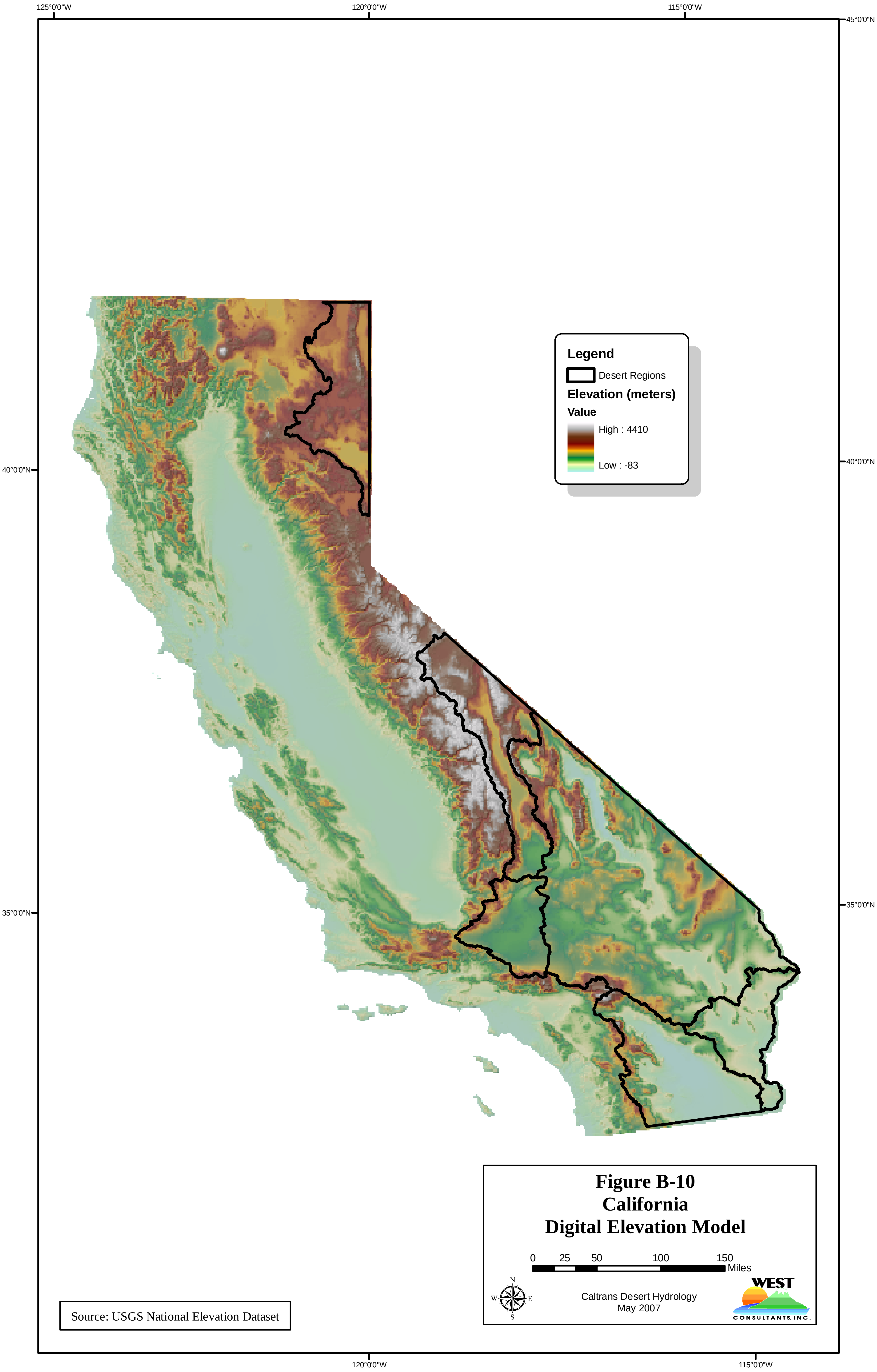

Figure B-10
California
Digital Elevation Model

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May 2007

Source: USGS National Elevation Dataset

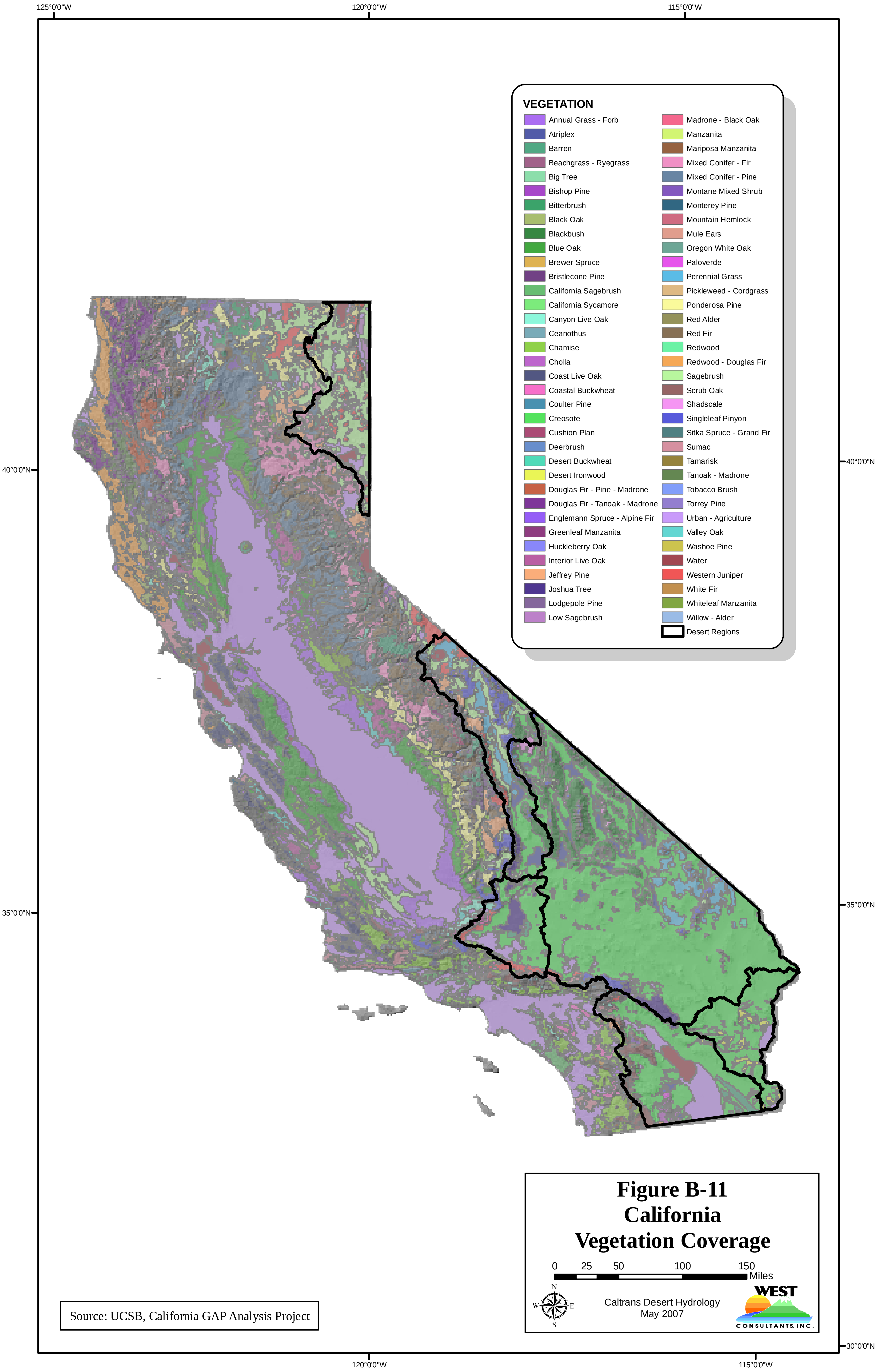

Figure B-11
California
Vegetation Coverage

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WEST
CONSULTANTS, INC.

Source: UCSB, California GAP Analysis Project

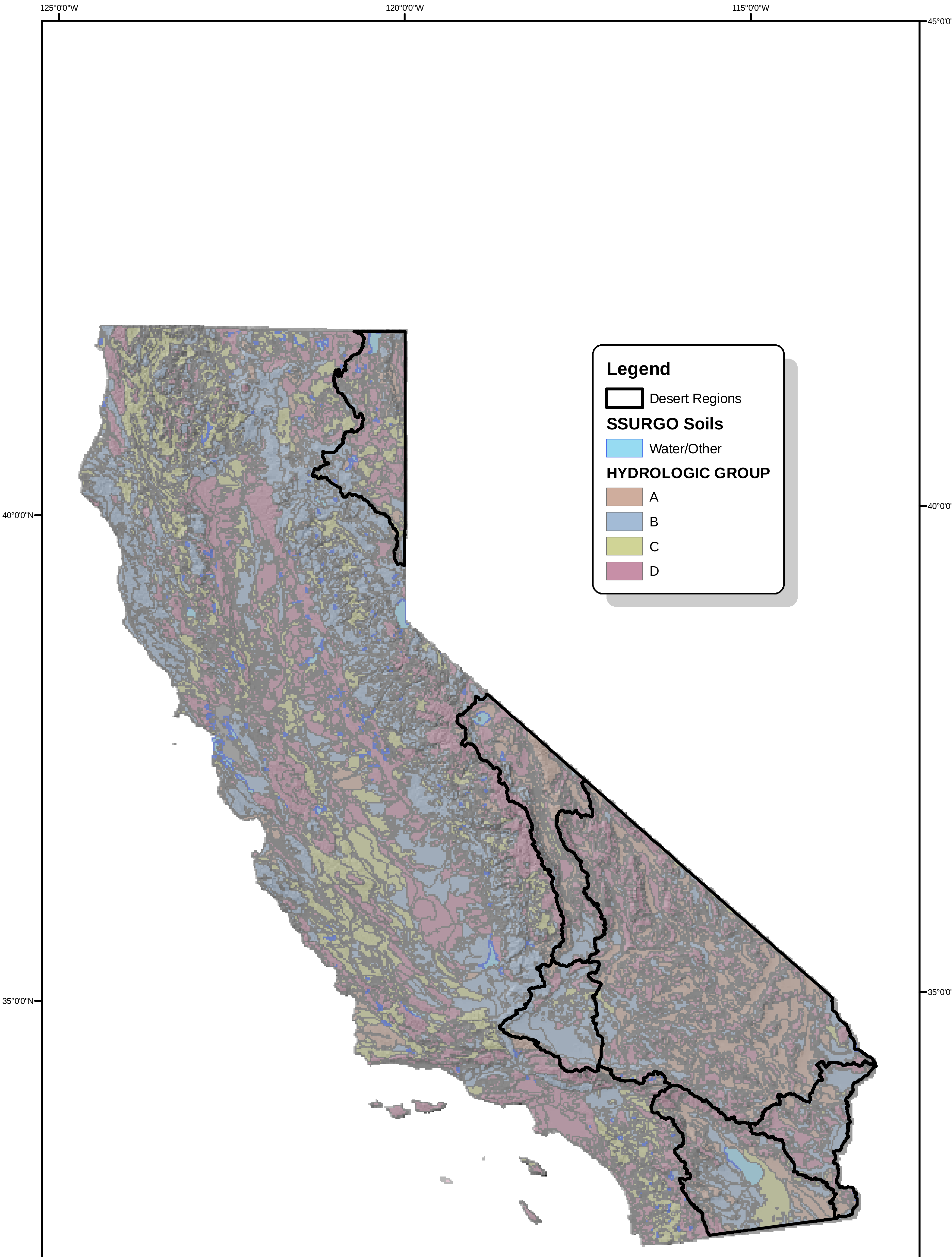

Figure B-12
Hydrologic Soil Groups

0 25 50 100 150 Miles

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WEST CONSULTANTS, INC.

Source: State Soil Geographic (STATSGO) data base
for California, USDA Natural Resources Conservation Service

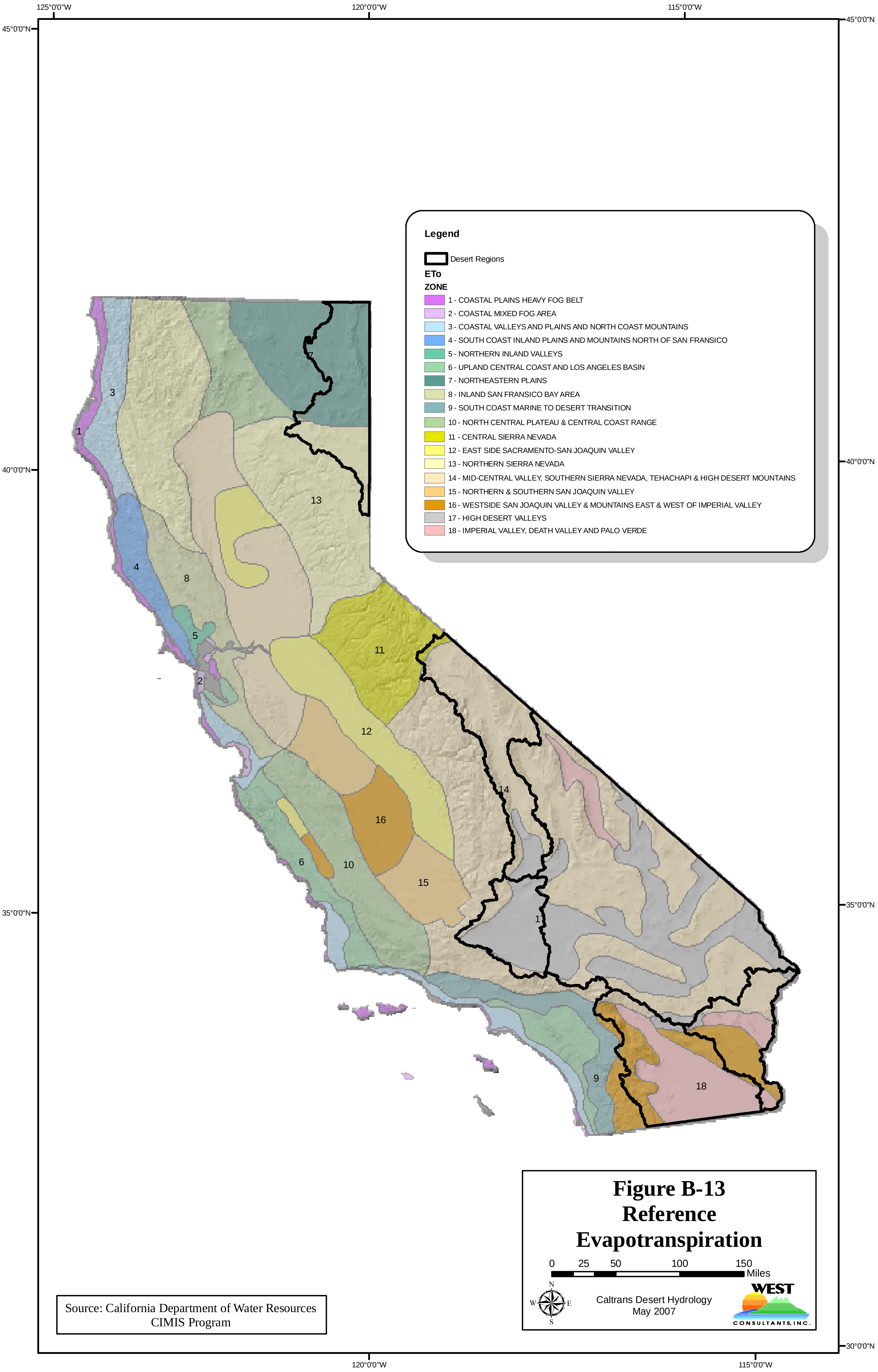

Figure B-13 Reference Evapotranspiration

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WEST CONSULTANTS, INC.

Source: California Department of Water Resources
CIMIS Program

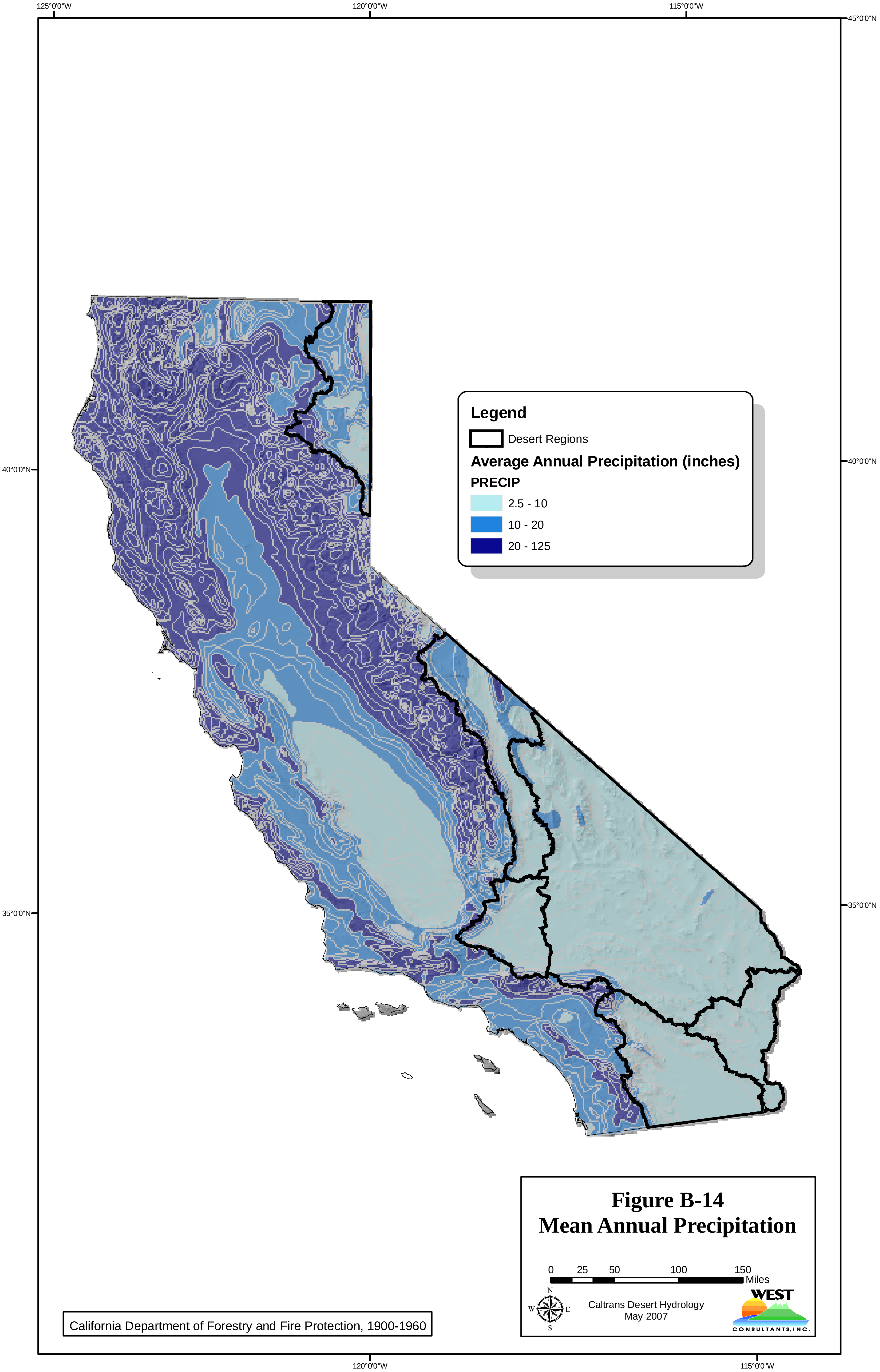

Figure B-14
Mean Annual Precipitation

California Department of Forestry and Fire Protection, 1900-1960

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WEST CONSULTANTS, INC.

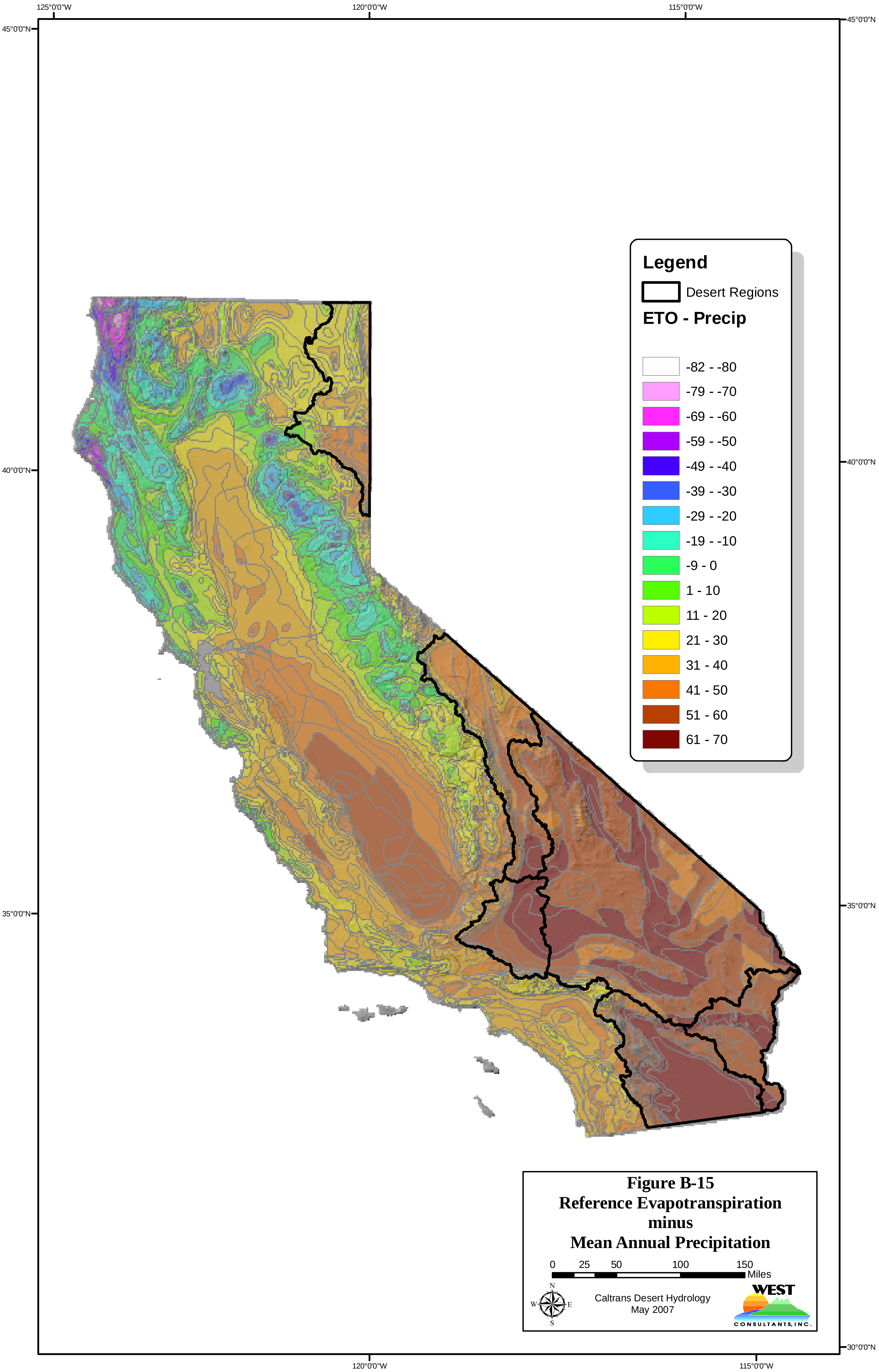

Figure B-15
Reference Evapotranspiration
minus
Mean Annual Precipitation

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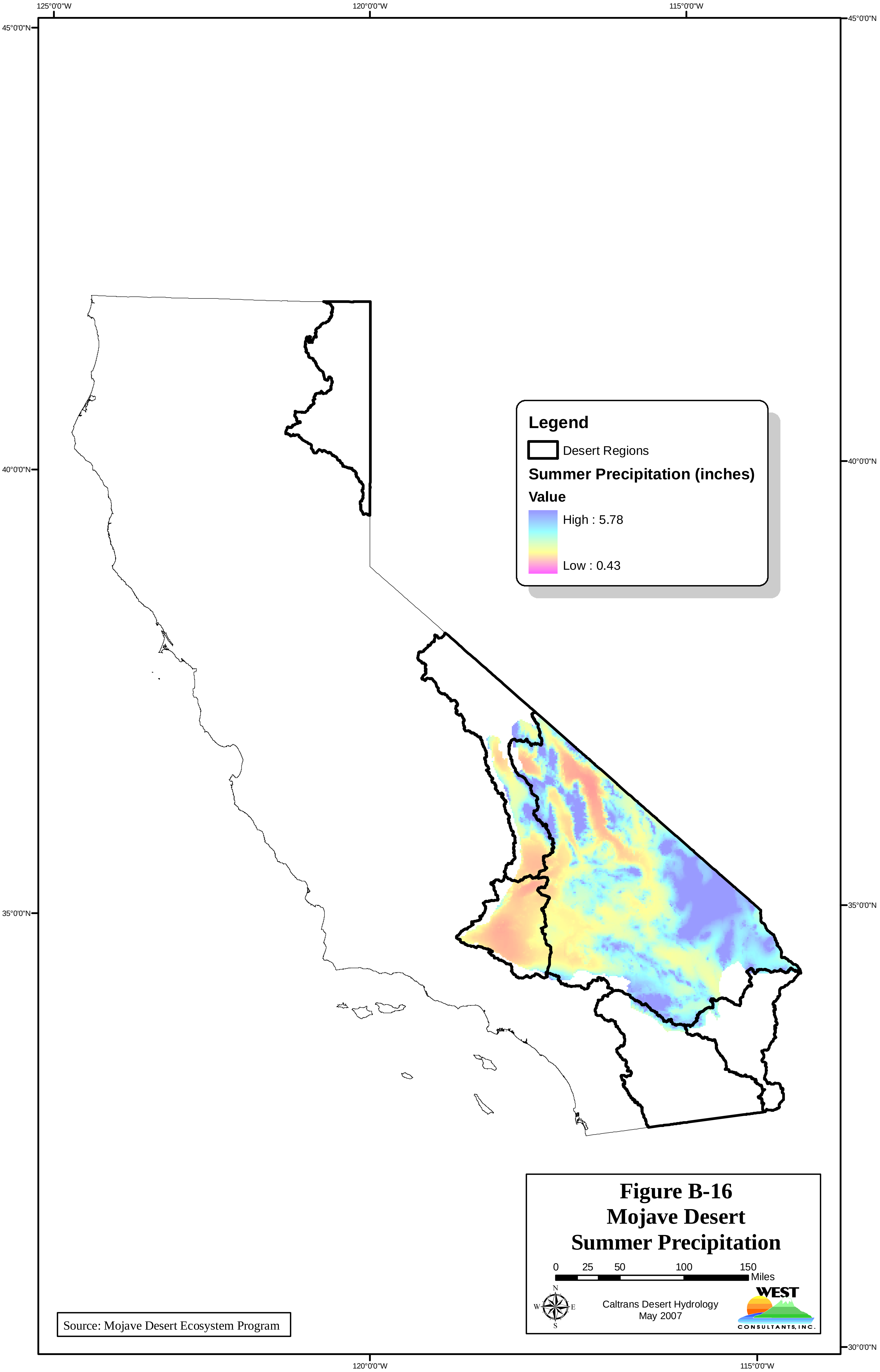

Figure B-16
Mojave Desert
Summer Precipitation

Caltrans Desert Hydrology
May 2007

Source: Mojave Desert Ecosystem Program

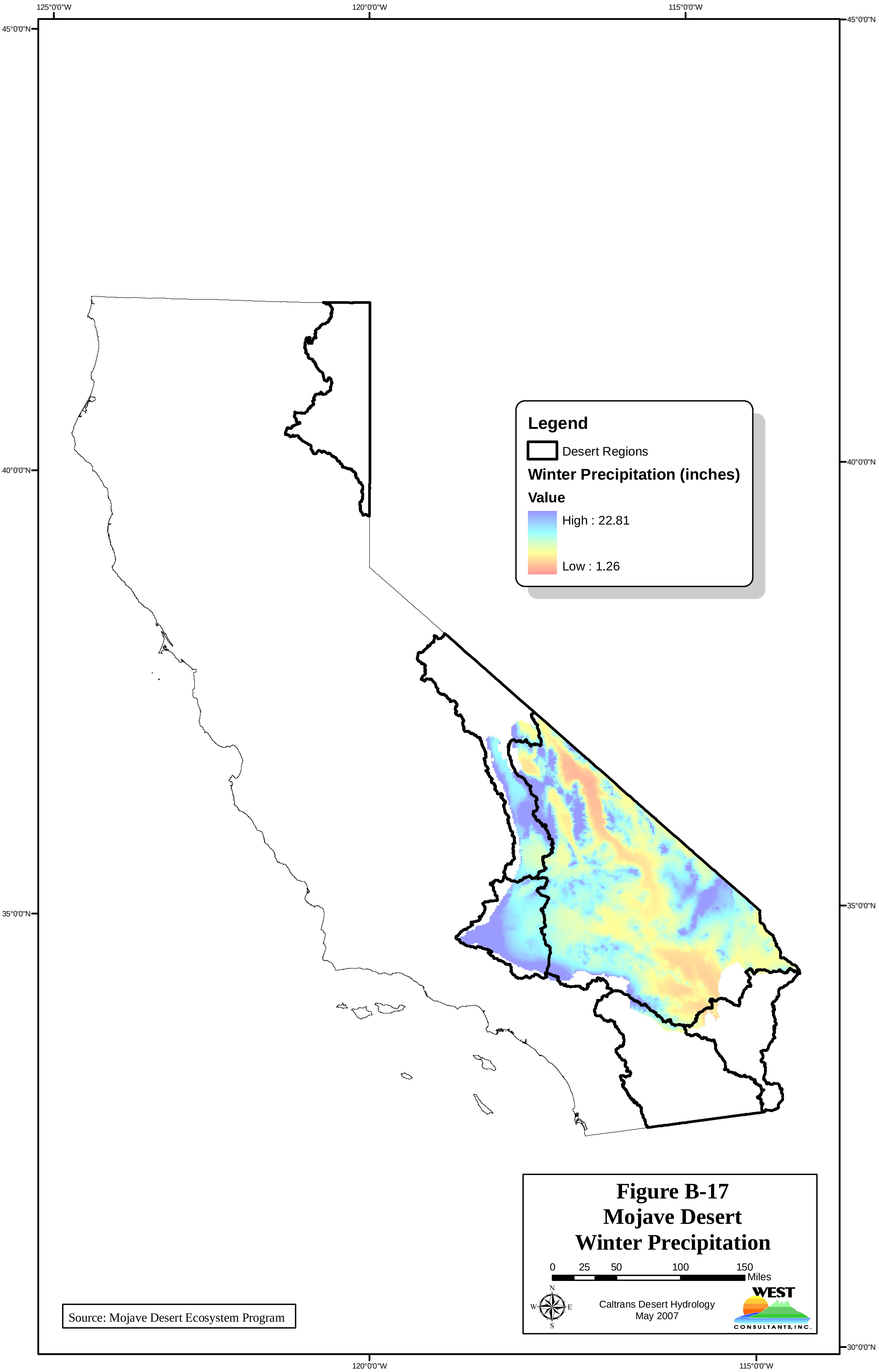

Figure B-17
Mojave Desert
Winter Precipitation

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WEST CONSULTANTS, INC.

Source: Mojave Desert Ecosystem Program

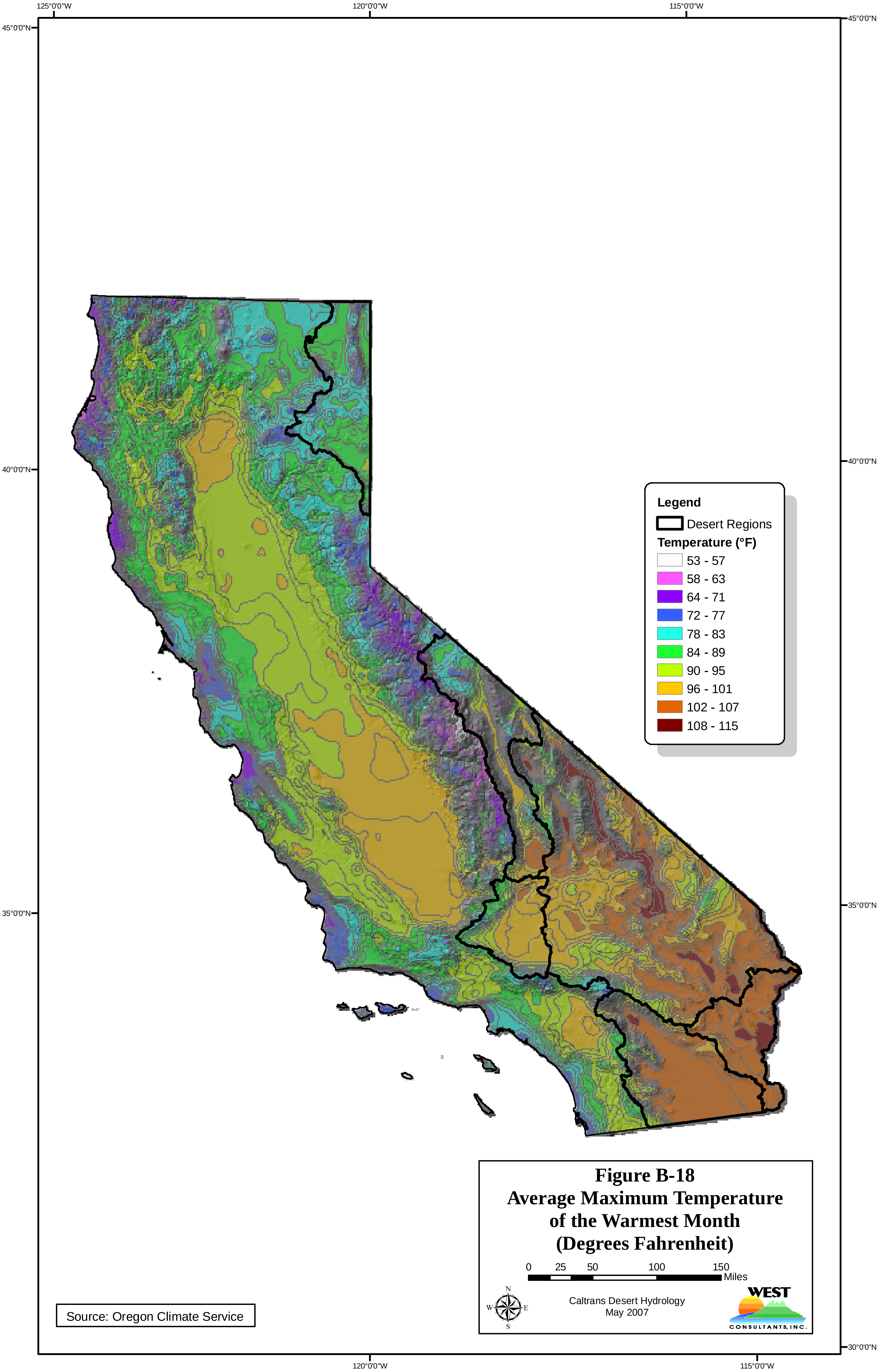

Figure B-18
Average Maximum Temperature of the Warmest Month (Degrees Fahrenheit)

Caltrans Desert Hydrology
May 2007

Source: Oregon Climate Service

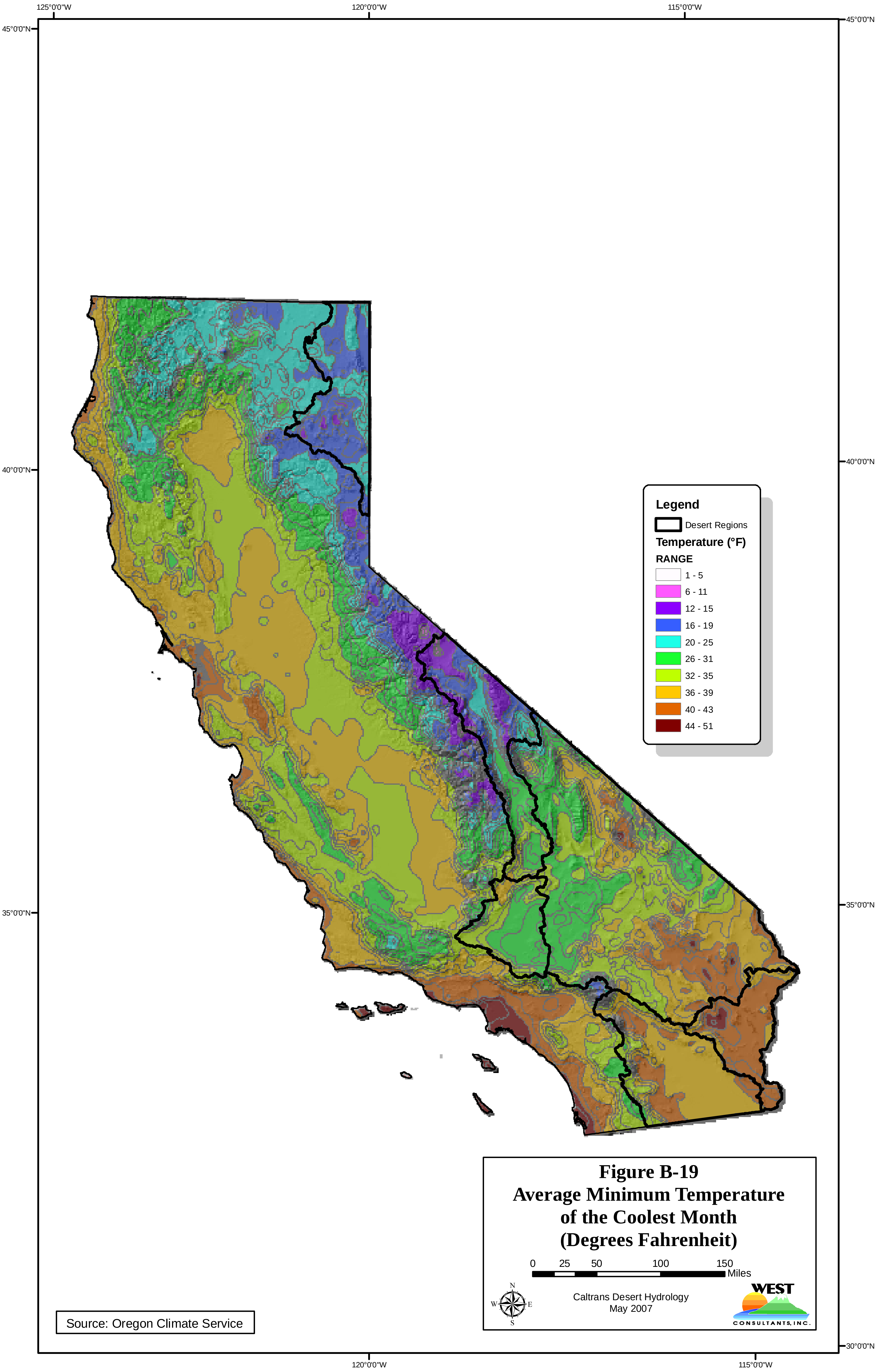

Figure B-19
Average Minimum Temperature of the Coolest Month (Degrees Fahrenheit)

Caltrans Desert Hydrology
May 2007

Source: Oregon Climate Service

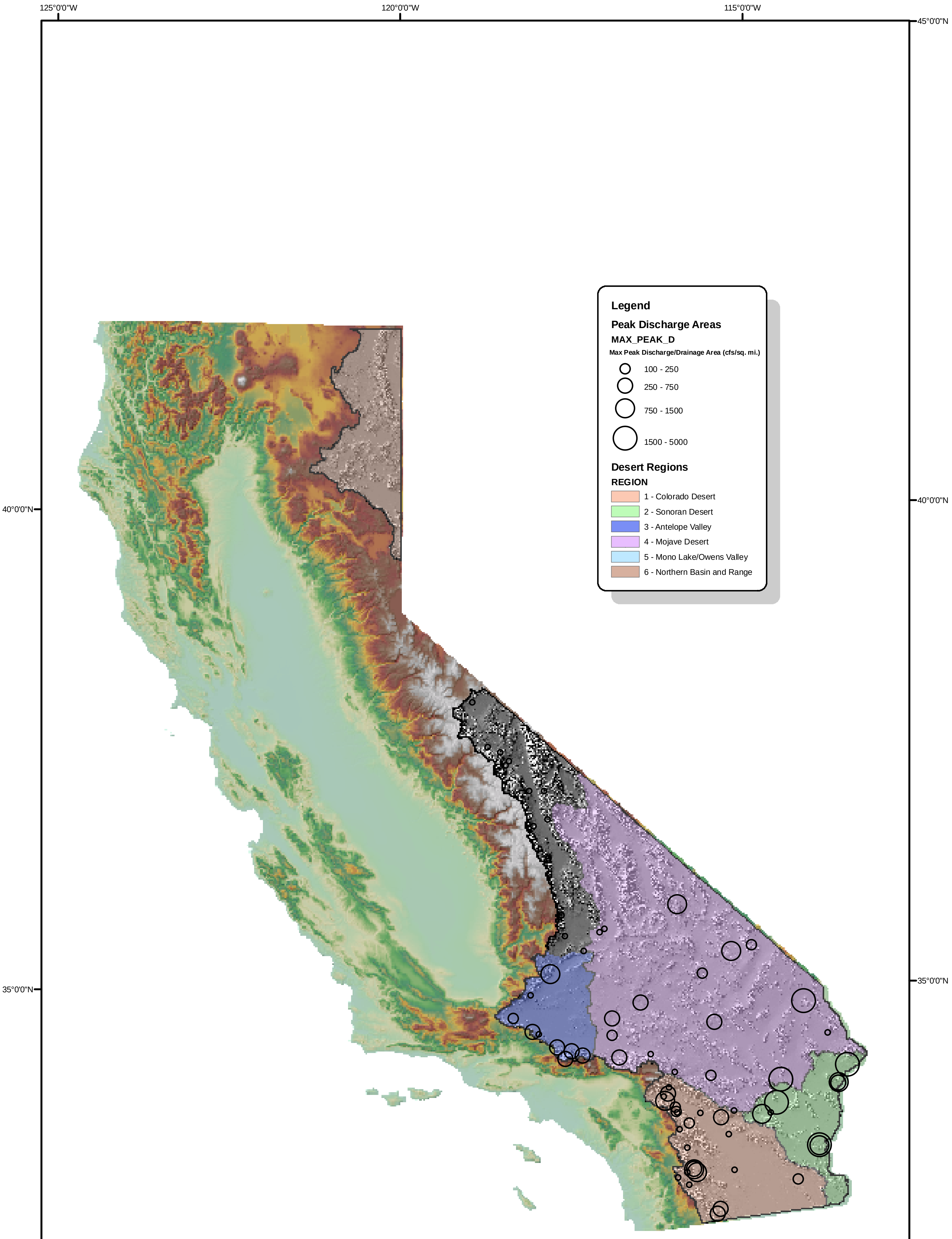

Figure B-20
Maximum Recorded Peak Discharge Divided by Drainage Area

0 25 50 100 150
Miles

Caltrans Desert Hydrology
May 2007

WEST
CONSULTANTS, INC.

Source: USGS stream gage data from Water Supply Paper 2433 (1997).
Note: No peak disharge data was provided in this report for NE California.

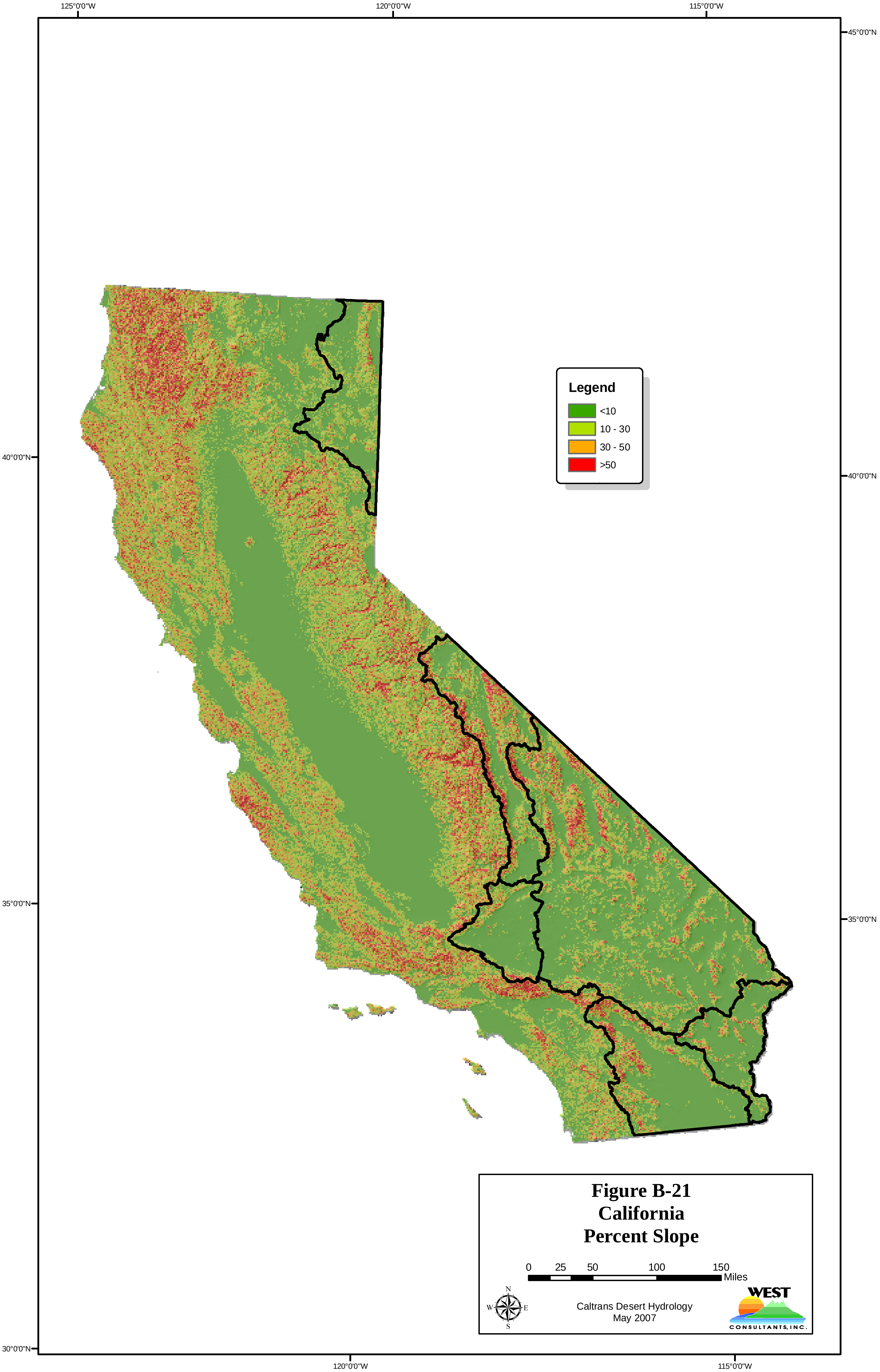

Figure B-21
California
Percent Slope

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May 2007

APPENDIX C

Peak Streamflow Gages and Precipitation Stations

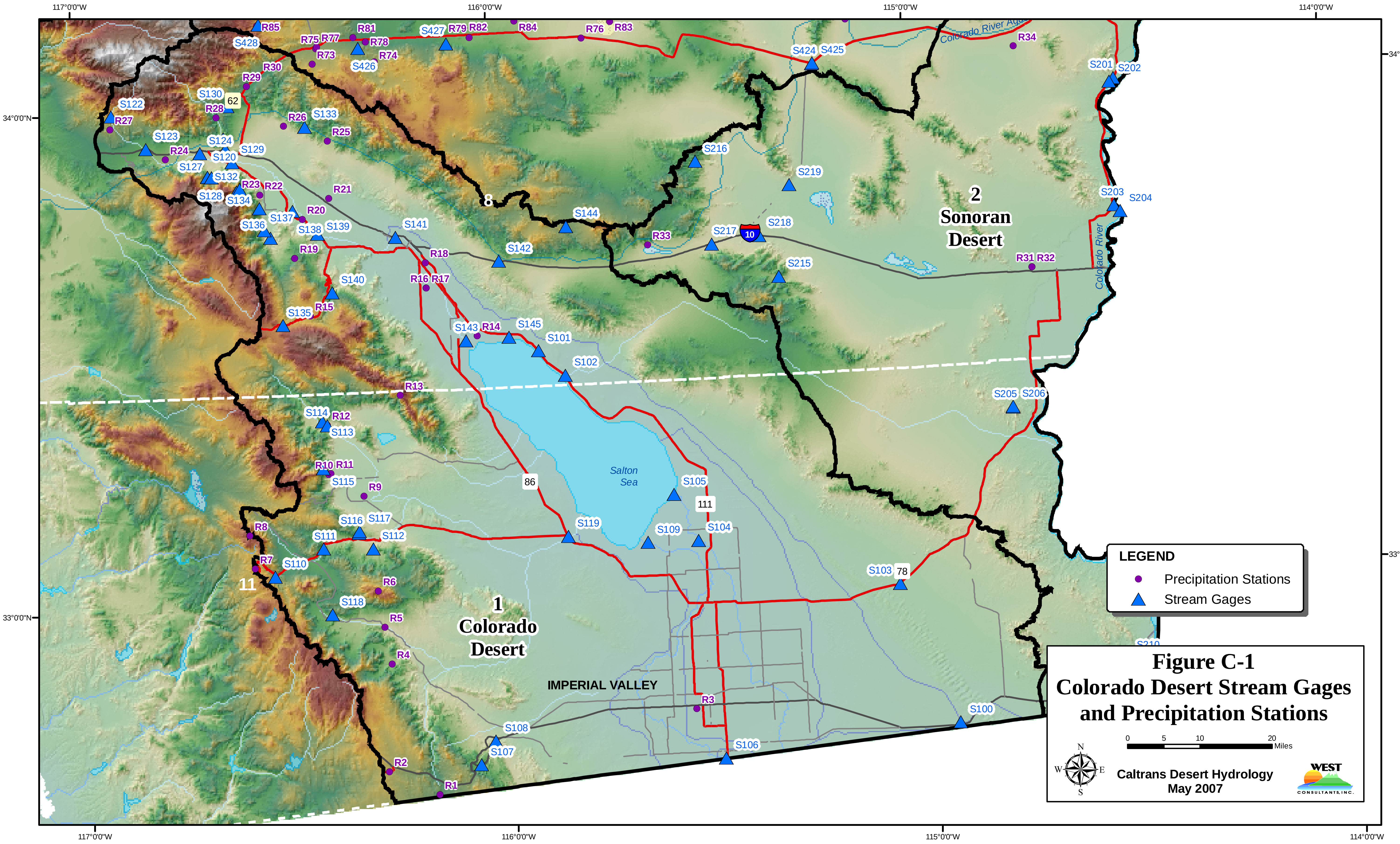

Figure C-1
Colorado Desert Stream Gages and Precipitation Stations

Colorado Desert - Region 1, Peak Flow Gages

ID	Station #	Station Name	Regulated	Latitude (Deg, Min, Sec)	Longitude (Deg, Min, Sec)	Drainage Area (sq mi)	Beginning of Peak Flow data	End of Peak Flow Data	Years of Record	Elevation at Gaging Station
S100	9527590	COACHELLA CANAL ABV ALL AMERICAN CANAL DIV	YES	32 45 51	114 56 38	0.00	10/3/2003	7/8/2005	2	161' Above Sea Level NGVD29
S101	10254020	BETZ WASH NR SALTON BEACH CA		33 29 53	115 54 16	5.95	1960	10/18/1972	14	
S102	10254050	SALT C NR MECCA		33 26 49	115 50 33	269.00	1/27/1961	1/5/1991	31	
S103	10254475	GLAMIS WASH A GLAMIS CA		32 59 53	115 04 10	0.60	12/25/1959	11/16/1973	15	340' Above Sea Level NGVD29
S104	10254670	ALAMO R AT DROP 3 NR CALIPATRIA CA		33 06 16	115 32 39	0.00	3/27/1980	4/26/2002	23	-190' Above Sea Level NGVD29
S105	10254730	ALAMO R NR NILAND CA	YES	33 11 56	115 35 46	0.00	4/7/1961	8/25/2003	43	
S106	10254970	NEW R AT INTERNATIONAL BOUNDARY AT CALEXICO CA	YES	32 39 57	115 30 08	0.00	3/13/1982	2/22/2004	23	-30' Above Sea Level NGVD29
S107	10255200	MYER C TRIB NR JACUMBA CA		32 40 25	116 04 50	0.11	9/1/1960	8/20/1973	14	1,880' Above Sea Level NGVD29
S108	10255230	MYER C TRIB NO 2 NR COYOTE WELLS CA		32 43 14	116 02 40	0.08	9/1/1960	8/20/1973	14	820' Above Sea Level NGVD29
S109	10255550	NEW R NR WESTMORLAND CA	YES	33 06 17	115 39 49	0.00	1/25/1962	4/3/2004	43	
S110	10255650	CHARIOT C NR JULIAN CA		33 03 58	116 33 08	7.95	2/21/1962	2/11/1973	12	2,820' Above Sea Level NGVD29
S111	10255700	SAN FELIPE C NR JULIAN CA		33 07 07	116 26 04	89.20	2/16/1959	3/1/1983	25	
S112	10255730	PINYON WASH NR BORREGO CA		33 06 55	116 19 00	19.60	1960	1973	14	1,400' Above Sea Level NGVD29
S113	10255800	COYOTE C NR BORREGO SPRINGS CA		33 22 25	116 25 36	144.00	7/28/1951	2/15/1986	36	1,200' Above Sea Level NGVD29
S114	10255805	COYOTE C BL BOX CANYON NR BORREGO SPRINGS CA		33 21 54	116 24 57	154.00	12/25/1983	3/14/1992	8	1,100' Above Sea Level NGVD29
S115	10255810	BORREGO PALM C NR BORREGO SPRINGS CA		33 16 44	116 25 45	21.80	7/28/1951	9/10/2004	53	1,200' Above Sea Level NGVD29
S116	10255820	YAQUI PASS WASH NR BORREGO CA		33 08 50	116 21 00	0.04	8/31/1960	1973	14	1,720' Above Sea Level NGVD29
S117	10255825	YAQUI PASS WASH NO 2 NR BORREGO CA		33 09 05	116 20 55	0.03	8/31/1960	3/9/1973	14	1,680' Above Sea Level NGVD29
S118	10255850	VALLECITO C NR JULIAN CA		32 59 10	116 25 10	39.70	7/31/1964	8/15/1983	20	1,860' Above Sea Level NGVD29
S119	10255885	SAN FELIPE C NR WESTMORLAND CA		33 07 26	115 51 08	1693.00	8/29/1961	8/26/1988	28	-180' Above Sea Level NGVD29
S120	10256000	WHITEWATER R A WHITEWATER CA		33 56 48	116 38 24	57.50	3/2/1938	3/27/1979	31	1,610' Above Sea Level NGVD29
S121	10256060	WHITEWATER R A WHITEWATER CUT A WHITEWATER CA	YES	33 55 31	116 38 07	59.10	2/15/1986	1/14/1990	4	1,360' Above Sea Level NGVD29
S122	10256200	SAN GORGONIO R NR BANNING CA		33 59 54	116 54 29	14.80	3/2/1938	1/3/1977	3	
S123	10256300	SAN GORGONIO R A BANNING CA		33 55 52	116 49 37	44.20	3/26/1981	11/30/1982	2	
S124	10256400	SAN GORGONIO R NR WHITE WATER CA		33 55 08	116 41 52	154.00	11/23/1965	1/5/1979	14	1,320' Above Sea Level NGVD29
S125	10256500	SNOW C NR WHITE WATER CA	YES	33 52 14	116 40 49	10.90	4/6/1924	1/11/2005	51	2,000' Above Sea Level NGVD29
S126	10256501	SNOW C AND DIV COMBINED CA		33 52 14	116 40 49	10.90	2/12/1992	3/15/2003	12	
S127	10257500	FALLS C NR WHITEWATER CA	YES	33 52 10	116 40 15	4.14	1/10/1995	1/11/2005	11	1,940' Above Sea Level NGVD29
S128	10257501	COMBINED FLOW FALLS C NR WHITEWATER + DIV CA		33 52 10	116 40 15	0.00	1/10/1995	3/15/2003	9	1,940' Above Sea Level NGVD29
S129	10257550	WHITEWATER R A WINDY PT NR WHITEWATER CA	YES	33 53 56	116 37 13	264.00	5/6/1985	12/25/2003	18	1,040' Above Sea Level NGVD29
S130	10257600	MISSION C NR DESERT HOT SPRINGS CA		34 00 40	116 37 38	35.60	7/28/1968	1/11/2005	37	
S131	10257710	CHINO CYN C NR PALM SPRINGS CA		33 50 21	116 36 45	3.82	3/8/1975	12/25/1983	10	2,260' Above Sea Level NGVD29
S132	10257720	CHINO CYN C BL TRAMWAY NR PALM SPRINGS CA	YES	33 50 39	116 36 16	4.71	11/18/1986	1/9/2005	19	2,100' Above Sea Level NGVD29
S133	10257800	LONG C NR DESERT HOT SPRINGS CA		33 57 53	116 26 35	19.60	8/7/1963	7/20/1979	17	1,560' Above Sea Level NGVD29
S134	10258000	TAHQUITZ C NR PALM SPRINGS CA		33 48 18	116 33 30	16.90	7/22/1948	1/11/2005	56	763' Above Sea Level NGVD29
S135	10258100	PALM CYN C TRIB NR ANZA CA		33 34 08	116 30 43	0.47	12/2/1961	11/16/1972	12	
S136	10258500	PALM CYN C NR PALM SPRINGS CA		33 44 42	116 32 05	93.10	8/1/1930	1/9/2005	71	700' Above Sea Level NGVD29
S137	10259000	ANDREAS C NR PALM SPRINGS CA		33 45 36	116 32 57	8.65	4/18/1949	12/25/2003	56	800' Above Sea Level NGVD29
S138	10259050	PALM CYN WASH NR CATHEDRAL CITY CA		33 47 47	116 28 48	0.00	8/10/1989	9/11/2004	15	
S139	10259100	WHITEWATER R A RANCHO MIRAGE CA		33 44 58	116 25 19	588.00	8/10/1989	1/11/2005	17	
S140	10259200	DEEP C NR PALM DESERT CA		33 37 52	116 23 29	30.60	1962	12/29/2004	44	1,440' Above Sea Level NGVD29
S141	10259300	WHITEWATER R A INDIO CA		33 44 14	116 14 07	1073.00	11/22/1965	1/11/2005	37	
S142	10259500	THERMAL CYN TRIB NR MECCA		33 40 50	115 59 25	0.18	1960	8/3/1973	14	1,640' Above Sea Level NGVD29
S143	10259540	WHITEWATER R NR MECCA		33 31 29	116 04 36	1495.00	8/15/1961	11/6/1996	37	1,495' Above Sea Level NGVD29
S144	10259600	COTTONWOOD WASH NR COTTONWOOD SPRINGS CA		33 44 40	115 49 35	0.65	9/5/1960	10/3/1972	14	3,080' Above Sea Level NGVD29
S145	10259920	WASTEWAY NO 1 NR MECCA	YES	33 31 40	115 58 23	0.00	3/29/1966	3/7/1971	6	

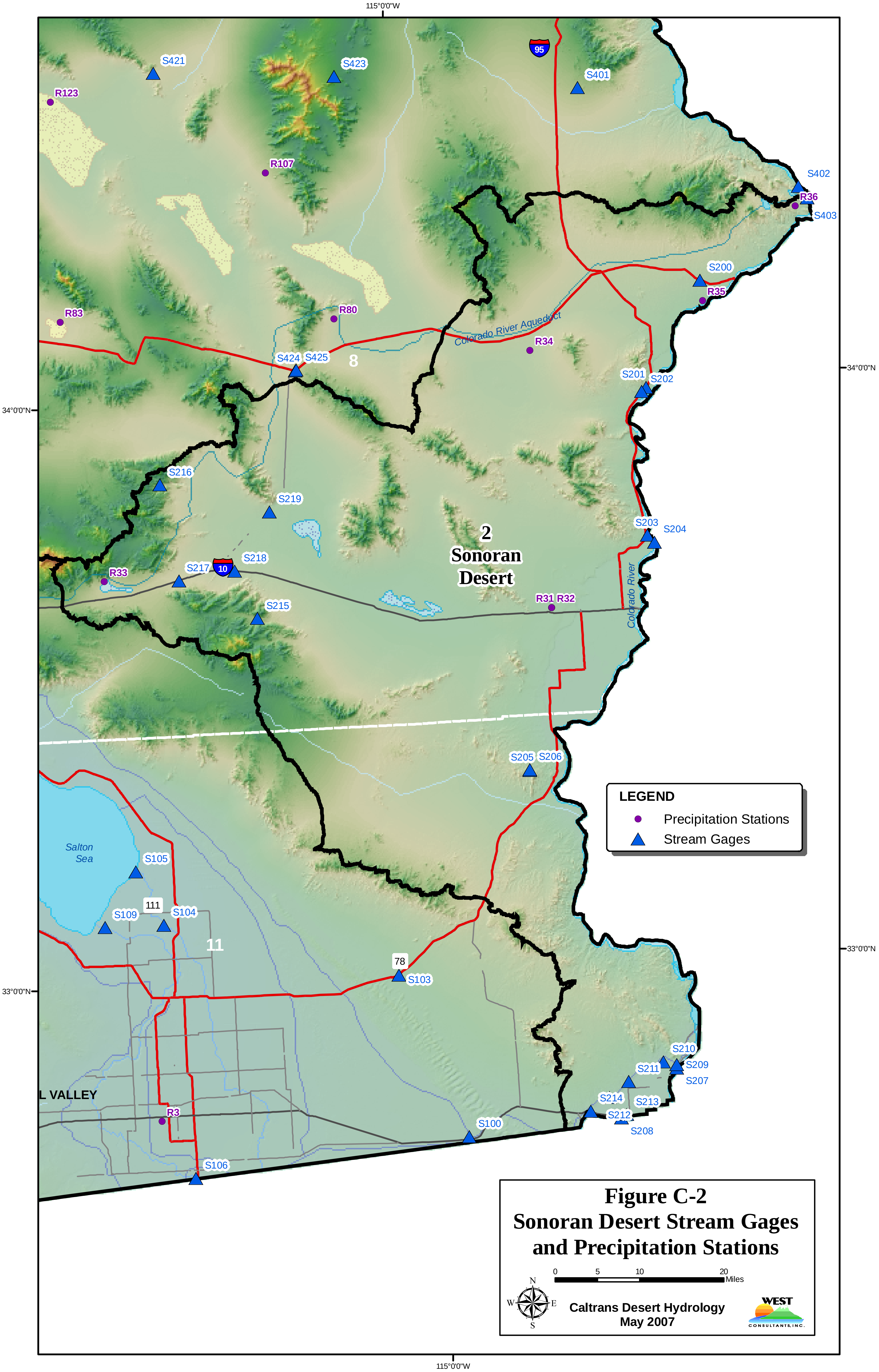

Figure C-2
Sonoran Desert Stream Gages and Precipitation Stations

Caltrans Desert Hydrology
May 2007

Sonoran Desert - Region 2, Peak Flow Gages

ID	Station #	Station Name	Regulated	Latitude (Deg, Min, Sec)	Longitude (Deg, Min, Sec)	Drainage Area (sq mi)	Beginning of Peak Flow data	End of Peak Flow Data	Years of Record	Elevation at Gaging Station (Feet above sea level)
S200	9428530	ARCH C NR EARP CA		34 09 55	114 22 20	1.52	21806	10/3/1972	15	600' NGVD29
S201	9428560	COLORADO R TRIB NO 2 NR VIDAL CA		33 59 11	114 29 45	0.39	9/1/1960	10/3/1972	14	350' NGVD29
S202	9428570	COLORADO R TRIB NR VIDAL CA		33 58 47	114 30 23	1.12	9/1/1960	5/26/1905	14	380' NGVD29
S203	9429000	PALO VERDE CANAL NEAR BLYTHE, CA	YES	33 43 55	114 30 40	0.00	8/2/2005	8/2/2005	1	274.1' NAVD88
S204	9429100	COLORADO RIVER BELOW PALO VERDE DAM, AZ-CA	YES	33 43 10	114 29 50	182200.00	8/19/1957	4/4/2005	23	260' NAVD88
S205	9429240	OGILBY WASH NR PALO VERDE CA		33 20 20	114 46 45	0.05	12/25/1959	10/6/1972	14	
S206	9429250	OGILBY WASH NO 2 NR PALO VERDE CA		33 20 25	114 46 45	0.02	12/25/1959	10/6/1972	14	
S207	9429600	COLORADO RIVER BELOW LAGUNA DAM, AZ-CA	YES	32 48 44	114 30 51	188600.00	9/16/1997	10/23/2004	5	120.81' NGVD29
S208	9521100	COLORADO R BLW YUMA MAIN CANAL WW AT YUMA, AZ	YES	32 43 54	114 37 55	246500.00	36461	38575	6	101.99' NGVD29
S209	9523200	RESERVATION MAIN CANAL NEAR YUMA, AZ	YES	32 49 05	114 30 50	0.00	5/16/2005	5/16/2005	1	180' NGVD29
S210	9523400	TITSINK CANAL NR YUMA, AZ	YES	32 49 28	114 32 28	0.00	5/10/2005	5/10/2005	1	145' NGVD29
S211	9523800	PONTIAC CANAL NR YUMA, AZ	YES	32 47 37	114 36 50	0.00	10/7/2004	10/7/2004	1	155' NGVD29
S212	9526200	YPSILANTI CANAL NR WINTERHAVEN, CA	YES	32 46 06	114 39 17	0.00	4/13/2000	38455	4	133' NGVD29
S213	9530000	RESERVATION MAIN DRAIN NO. 4 NR YUMA, AZ		32 44 14	114 37 16	0.00	2/28/2005	2/28/2005	1	127' NGVD29
S214	9530500	DRAIN 8-B NEAR WINTERHAVEN, CA		32 44 46	114 41 37	0.00	10/19/2004	10/19/2004	1	118' NGVD29
S215	10253540	CORN SPRINGS WASH NR DESERT CENTER CA		33 37 30	115 19 20	24.10	8/2/1964	8/21/1971	8	
S216	10253600	EAGLE C A EAGLE MOUTAIN CA		33 51 46	115 30 34	7.71	8/23/1961	5/19/1905	6	1,430' NGVD29
S217	10253700	PALEN DRY LK TRIB NR DESERT CENTER CA		33 41 45	115 28 45	0.04	9/6/1960	1/18/1973	14	
S218	10253750	MONUMENT WASH NR DESERT CENTER CA		33 42 30	115 21 50	4.29	7/22/1960	1/18/1973	14	
S219	10253800	COXCOMB WASH NR DESERT CENTER CA		33 48 25	115 17 10	0.03	3/24/1960	10/9/1972	14	

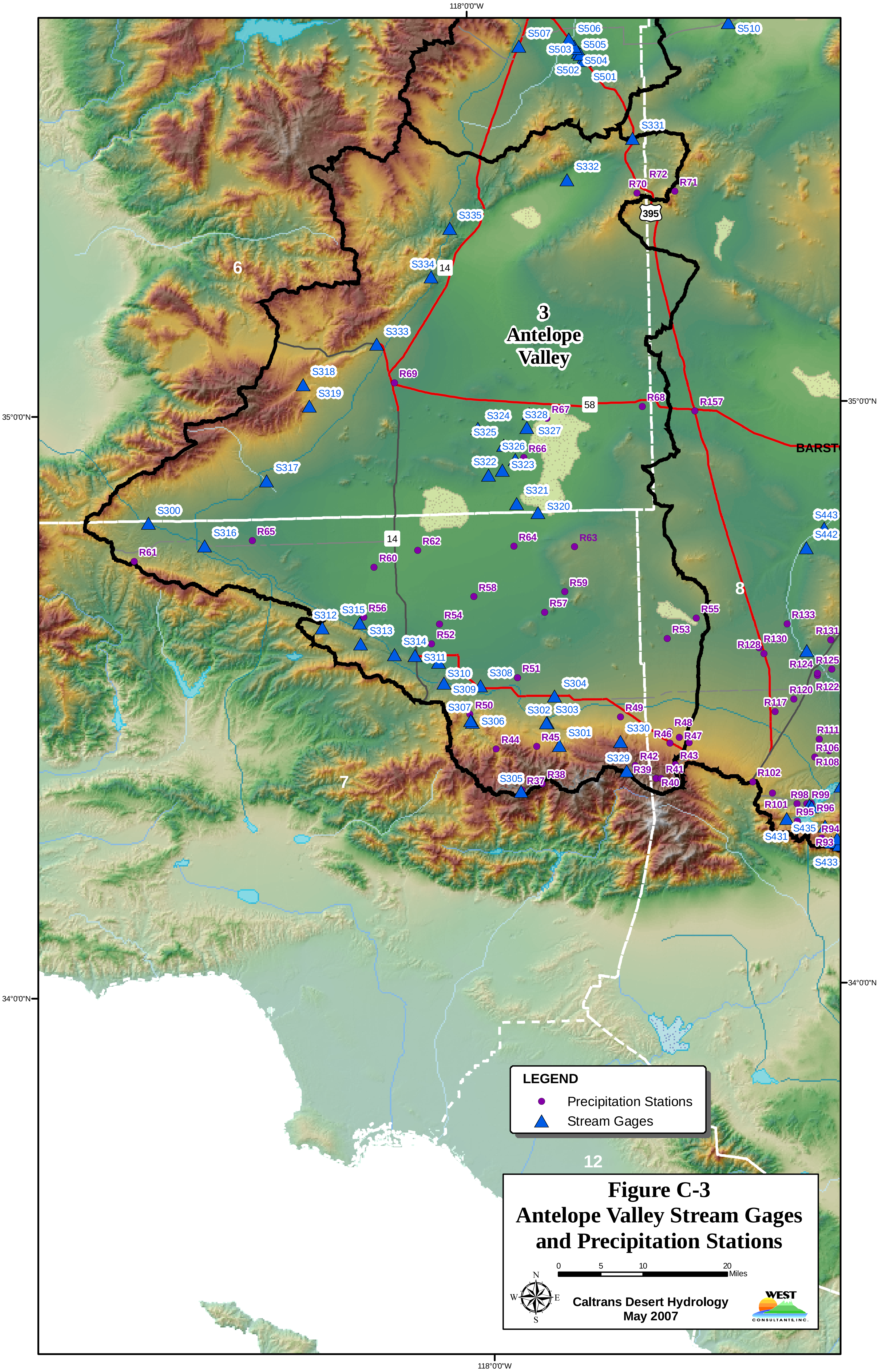

Figure C-3
Antelope Valley Stream Gages and Precipitation Stations

Caltrans Desert Hydrology
May 2007

Antelope Valley - Region 3, Peak Flow Gages

ID	Station #	Station Name	Regulated	Latitude (Deg, Min, Sec)	Longitude (Deg, Min, Sec)	Drainage Area (sq mi)	Beginning of Peak Flow data	End of Peak Flow Data	Years of Record	Elevation at Gaging Station (Feet above sea level)
S300	10260776	EB CALIFORNIA AQUEDUCT A ALAMO PP NR GORMAN CA	YES	34 48 56	118 41 03	0.00	37713	5/18/2005	3	
S301	10263500	BIG ROCK C NR VALYERMO CA		34 25 15	117 50 19	22.90	4/10/1923	1/9/2005	82	4,050' Above Sea Level NGVD29
S302	10263630	BIG ROCK C AB PALLETT C NR VALYERMO CA		34 27 37	117 51 48	34.40	2/12/2003	1/9/2005	3	3,555' Above Sea Level NGVD29
S303	10263665	PALLETT C A BIG ROCK C NR VALYERMO CA		34 27 38	117 51 50	15.10	2/12/2003	1/9/2005	3	
S304	10263675	BIG ROCK C WASH A HWY 138 NR LLANO CA		34 30 21	117 50 45	53.10	2/8/1989	3/1/1991	3	
S305	10263900	BUCKHORN C NR VALYERMO CA		34 20 35	117 55 13	0.48	11/6/1960	1/9/2005	33	
S306	10264000	LITTLE ROCK C AB LTTLE ROCK RES NR LITTLEROCK CA		34 27 50	118 01 05	49.00	4/26/1931	1/9/2005	50	3,310' Above Sea Level NGVD29
S307	10264100	SANTIAGO CYN C AB LITTLE ROCK C NR LITTLEROCK CA		34 28 02	118 01 17	11.30	2/12/2003	2/21/2005	3	3,300' Above Sea Level NGVD29
S308	10264502	PEACH TREE C NR LITTLE ROCK CA		34 31 34	117 59 58	0.08	32770	33316	3	
S309	10264503	BARREL SPRINGS TRIB A CA AQ XING NR PALMDALE CA		34 31 56	118 04 32	0.00	1/4/1989	1/4/1989	1	
S310	10264508	SOMERSET C A PALMDALE CA		34 34 07	118 05 06	0.16	2/9/1989	3/1/1991	3	
S311	10264510	INN C A PALMDALE CA		34 34 51	118 08 05	0.03	3/5/1990	3/1/1991	2	
S312	10264520	AMARGOSA C TRIB NR LEONA VALLEY CA		34 37 51	118 19 32	0.05	2/11/1959	32493	16	
S313	10264530	PINE C NR PALMDALE CA		34 36 09	118 14 48	1.78	1/6/1959	12/29/2004	42	
S314	10264550	CITY RANCH C NR PALMDALE CA		34 35 00	118 10 36	0.39	12/20/1988	3/26/1991	3	
S315	10264555	ESTATES C NR QUARTZ HILL CA		34 38 19	118 14 52	0.10	5/15/1989	3/1/1991	3	
S316	10264560	SPENCER CYN C NR FAIRMONT CA		34 46 32	118 34 06	3.60	1/6/1959	1/10/2005	43	2,940' Above Sea Level NGVD29
S317	10264590	COTTONWOOD C NR ROSAMOND CA		34 53 08	118 26 11	35.70	5/19/1905	6/7/1972	7	
S318	10264600	OAK C NR MOJAVE CA		35 03 00	118 21 25	15.80	4/18/1958	3/25/1989	30	4,080' Above Sea Level NGVD29
S319	10264605	JOSHUA C NR MOJAVE CA		35 00 45	118 20 40	3.83	1/6/1959		21	3,800' Above Sea Level NGVD29
S320	10264636	SLED TRACK CN A LANCASTER BLVD NR ROGERS LAKE CA		34 49 19	117 52 20	0.00	11/21/1996	2/13/2001	3	2,275' Above Sea Level NGVD29
S321	10264640	BUCKHORN C A E 120TH AVE NR ROGERS LAKE CA		34 50 18	117 54 59	0.00	9/25/1997	2/13/2001	5	2,270' Above Sea Level NGVD29
S322	10264646	S DRAINAGE BISSELL/ROSAMOND HILLS NR EDWARDS AFB		34 53 18	117 58 23	9.25	6/19/1905	6/21/1905	3	2,475' Above Sea Level NGVD29
S323	10264650	BISSELL HILLS C A EDWARDS AFB CA		34 53 47	117 56 40	0.76	12/16/1988	12/16/1988	1	
S324	10264656	MOJAVE C NR EDWARDS CA		34 58 07	117 59 38	152.00	6/19/1905	6/21/1905	3	2,410' Above Sea Level NGVD29
S325	10264658	MOJAVE C A FORBES AVE A EDWARDS AFB CA		34 56 20	117 56 25	168.00	6/19/1905	8/1/2000	3	2,475' Above Sea Level NGVD29
S326	10264660	MOJAVE C A ROSAMOND BLVD A EDWARDS CA		34 54 51	117 55 00	175.00	6/19/1905	1/11/2001	5	2,310' Above Sea Level NGVD29
S327	10264673	N BASE TRIB A RR CROSSING NR EDWARDS CA		34 59 32	117 53 09	0.00	6/19/1905	6/21/1905	3	2,320' Above Sea Level NGVD29
S328	10264675	ROGERS LK TRIB A EDWARDS AFB CA		34 58 06	117 53 29	1.73	4/14/1989	3/6/2001	12	
S329	10264680	MESCAL C TRIB A BIG PINES CA		34 22 28	117 41 59	0.05	5/14/1905	5/14/1973	12	
S330	10264682	MESCAL C NR PINON HILLS CA		34 25 32	117 42 43	5.41	9/3/2003	1/9/2005	3	4,800' Above Sea Level NGVD29
S331	10264700	PEEWEE C NR RANDSBURG CA		35 27 40	117 39 20	0.14	1967	5/14/1973	15	
S332	10264710	GOLER GULCH NR RANDSBURG CA		35 23 34	117 47 43	41.30	8/8/1967	5/25/1905	6	
S333	10264740	CACHE C NR MOJAVE CA		35 07 01	118 12 05	96.50	23832	6/7/1972	8	3,280' Above Sea Level NGVD29
S334	10264750	PINE TREE C NR MOJAVE CA		35 13 50	118 05 07	34.16	7/30/1959	1/16/1979	20	2,720' Above Sea Level NGVD29
S335	10264770	COTTONWOOD C NR CANTIL CA		35 18 50	118 02 38	163.00	8/8/1963	6/7/1972	7	2,410' Above Sea Level NGVD29
S336	F122-R	Pallett Creek at Valyermo Highway								

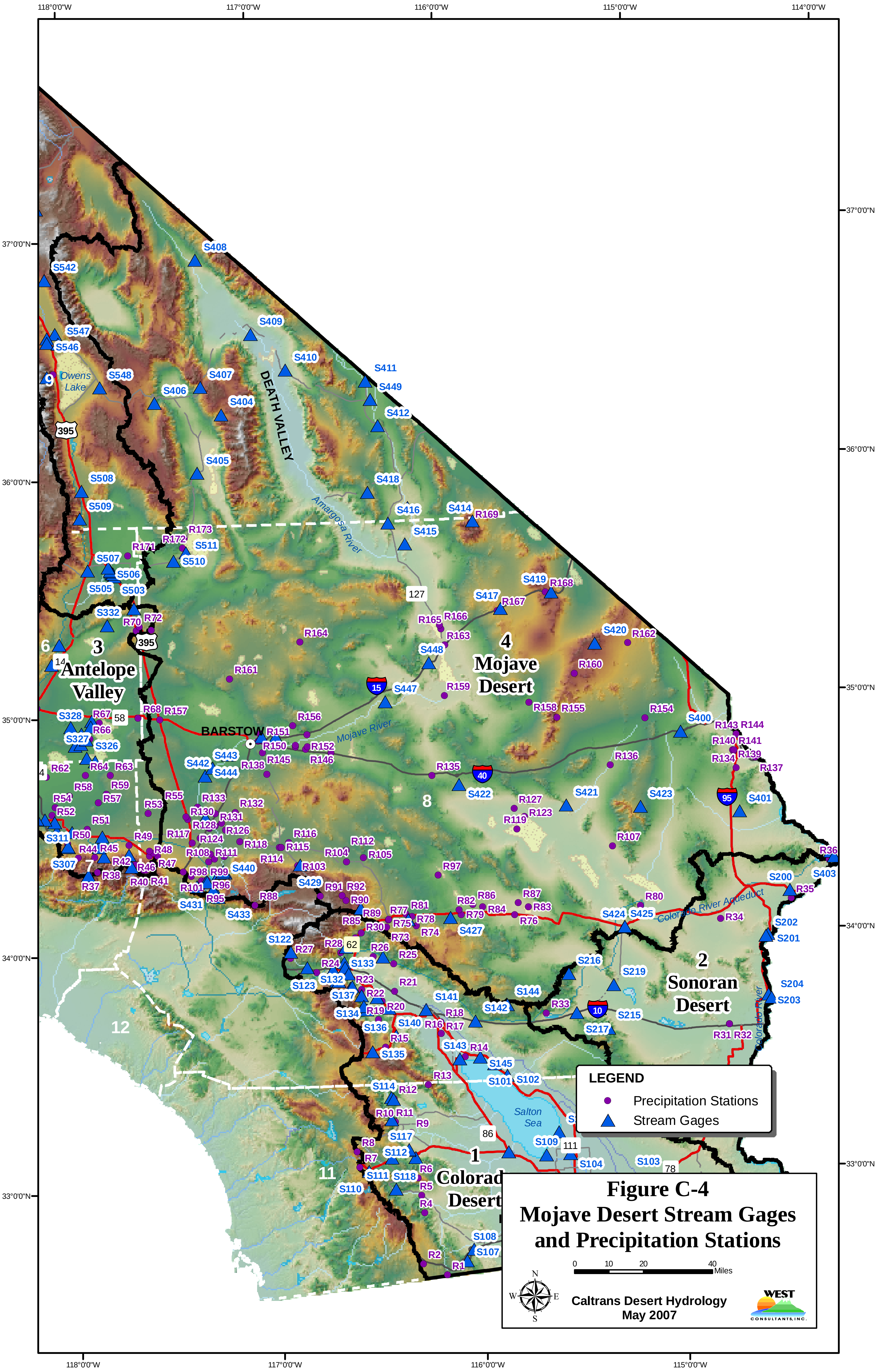

Figure C-4
Mojave Desert Stream Gages and Precipitation Stations

Caltrans Desert Hydrology
May 2007

Mojave Desert - Region 4, Peak Flow Gages

ID	Station #	Station Name	Regulated	Latitude (Deg, Min, Sec)	Longitude (Deg, Min, Sec)	Drainage Area (sq mi)	Beginning of Peak Flow data	End of Peak Flow Data	Years of Record	Elevation at Gaging Station (Feet above sea level)
S400	9423400	TIN CAN C NR NEEDLES CA		34 51 25	114 52 55	0.04	11/11/1958	2/21/1973	15	
S401	9424050	CHEMEHUEVI WASH TRIB NR NEEDLES CA		34 30 30	114 36 10	2.04	12/25/1959	11/14/1972	14	1,600' Above Sea Level NGVD29
S402	9427500	LAKE HAVASU NEAR PARKER DAM, AZ-CA	YES	34 18 58	114 09 23	182700.00	4/18/1943	6/4/1953	2	400.54' Above Sea Level NGVD29
S403	9427520	COLORADO RIVER BELOW PARKER DAM, AZ-CA	YES	34 17 44	114 08 22	182700.00	2/8/1937	9/14/2005	6	300.54' Above Sea Level NGVD29
S404	10250600	WILDROSE C NR WILDROSE STATION CA		36 15 54	117 10 40	23.50	8/5/1961	9/7/1975	15	
S405	10250720	ONYX C NR BALLARAT CA		36 01 20	117 18 45	0.52	9/20/1963	5/26/1905	11	
S406	10250800	DARWIN C NR DARWIN CA		36 19 14	117 31 23	173.00	8/8/1963	12/26/1988	27	
S407	10250870	TOWNE C NR PANAMINT SPRINGS CA		36 22 56	117 16 58	0.27	5/17/1905	5/26/1905	10	4,750' Above Sea Level NGVD29
S408	10251000	BIG DIP C NR STOVEPIPE WELLS CA		36 55 05	117 17 35	0.95	11/11/1958	10/20/1972	15	
S409	10251100	SALT C NR STOVEPIPE WELLS CA		36 35 58	117 00 46		7/30/1974	4/15/1988	15	
S410	10251200	SPRING C A FURNACE C INN CA		36 26 40	116 50 15	0.21	9/12/1959	2/11/1973	15	
S411	10251259	Amargosa River at Hwy 127 nr CA-NV State Line		36 23 12	116 25 22	1542.00	2/26/1993	8/15/2004	8	2,060' Above Sea Level NGVD29
S412	10251280	Amargosa River nr Eagle Mtn blw Death Vly Jct		36 11 48	116 22 06	2632.00	2/24/1998	2/24/1998	1	1,180' Above Sea Level NGVD29
S413	10251300	AMARGOSA RIVER AT TECOPA, CA		35 50 55	116 13 45	3090.00	9/26/1962	2/22/2005	30	1,310' Above Sea Level NGVD29
S414	10251350	HORSETHIEF C NR TECOPA CA		35 46 52	115 53 50	3.06	8/23/1961	8/16/1970	10	
S415	10251375	Amargosa R at Dumont Dunes nr Death Vly, CA		35 41 45	116 15 02	3284.00	2/24/1998	1/11/2001	4	660' Above Sea Level NGVD29
S416	10251400	IBEX C NR TECOPA CA		35 47 15	116 20 00	0.20	9/13/1959	10/3/1972	15	
S417	10251500	YUCCA C NR YUCCA GROVE CA		35 24 30	115 46 20	0.03	8/7/1959	2/28/1973	15	
S418	10251600	SALSBERRY C NR SHOSHONE CA		35 55 10	116 26 05		5/12/1905	10/3/1972	15	
S419	10252300	CHINA SPRING C NR MOUNTAIN PASS CA		35 28 05	115 30 30	0.94	5/12/1905	5/26/1905	15	
S420	10252550	CARUTHERS C NR IVANPAH CA		35 14 42	115 17 53	0.84	10/18/1963	12/29/2004	42	5,640' Above Sea Level NGVD29
S421	10252700	CREOSOTE C NR CADIZ CA		34 34 15	115 28 55	0.02	8/17/1959	2/21/1973	15	
S422	10253000	GOURD C NR LUDLOW CA		34 40 35	116 01 20	0.34	5/12/1905	12/29/2004	37	1,720' Above Sea Level NGVD29
S423	10253080	SUNFLOWER WASH NR ESSEX CA		34 33 00	115 06 25	3.31	9/18/1963	5/23/1905	8	
S424	10253250	GRANITE WASH NR RICE CA		34 02 50	115 13 05		1/12/1960	5/26/1905	14	
S425	10253255	GRANITE WASH NO 2 NR RICE CA		34 02 55	115 13 00	0.01	1/12/1960	5/26/1905	14	
S426	10253320	QUAIL WASH NR JOSHUA TREE CA		34 07 04	116 18 27	100.00	5/17/1905	6/1/1905	16	
S427	10253350	FORTYNINE PALMS C NR TWENTYNINE PALMS CA		34 07 12	116 05 43	8.55	5/14/1905	7/20/1979	18	2,315' Above Sea Level NGVD29
S428	10260200	PIPES C NR YUCCA VALLEY CA		34 10 19	116 32 45	15.10	5/12/1905	7/20/1979	21	4,440' Above Sea Level NGVD29
S429	10260400	CUSHENBURY C NR LUCERNE CA		34 21 52	116 50 42	6.36	4/11/1958	7/20/1979	20	
S430	10260500	DEEP C NR HESPERIA CA		34 20 28	117 13 39	134.00	3/12/1906	10/20/2004	86	3,050' Above Sea Level NGVD29
S431	10260550	WF MOJAVE R AB SILVERWOOD LAKE NR HESPERIA CA		34 17 06	117 22 16	3.22	2/20/1996	12/25/2003	8	3,550' Above Sea Level NGVD29
S432	10260620	HOUSTON C AB LK GREGORY A CRESTLINE CA		34 14 33	117 16 48	0.35	2/19/1980	2/19/1993	14	4,540' Above Sea Level NGVD29
S433	10260630	ABONDIGAS C AB LK GREGORY A CRESTLINE CA		34 14 16	117 15 51	1.15	1/29/1980	2/8/1993	13	4,550' Above Sea Level NGVD29
S434	10260650	HOUSTON C BL LK GREGORY A CRESTLINE CA	YES	34 14 54	117 16 05	2.68	1/29/1980	1/7/1993	14	4,440' Above Sea Level NGVD29
S435	10260700	EF OF WF MOJAVE R AB SILVERWOOD LK NR HESPERIA CA		34 16 13	117 17 31	11.20	2/20/1996	2/26/2004	9	3,590' Above Sea Level NGVD29
S436	10260780	EB CA AQUEDUCT A MOJAVE SIPHON PP NR HESPERIA CA	YES	34 18 25	117 19 24		6/22/2003	8/15/2004	2	3,182' Above Sea Level NGVD29
S437	10260820	WF MOJAVE R BL SILVERWOOD LK CA	YES	34 18 15	117 19 06	34.00	1/29/1981	12/31/2003	10	3,180' Above Sea Level NGVD29
S438	10260950	WF MOJAVE R AB MOJAVE R FORKS RES NR HESPERIA CA	YES	34 20 20	117 15 25	70.30	3/8/1975	1/11/2005	31	3,050' Above Sea Level NGVD29
S439	10261000	WF MOJAVE R NR HESPERIA CA		34 20 27	117 14 24	70.30	3/5/1907	11/29/1970	49	3,050' Above Sea Level NGVD29
S440	10261100	MOJAVE R BL FORKS RES NR HESPERIA CA		34 20 45	117 14 14	209.00	12/24/1971	1/26/1997	20	2,956' Above Sea Level NGVD29
S441	10261500	MOJAVE R A LO NARROWS NR VICTORVILLE CA	YES	34 34 23	117 19 11	513.00	4/27/1931	1/11/2005	75	2,643.01' Above Sea Level NGVD29
S442	10261800	BEACON C A HELENDALE CA		34 45 00	117 18 53	0.72	9/13/1959	6/19/1905	27	2,450' Above Sea Level NGVD29
S443	10261900	MOJAVE R A W XING NR HELENDALE CA		34 46 58	117 16 35	958.00	3/11/1966	3/3/1970	5	
S444	10262000	MOJAVE R NR HODGE CA	YES	34 50 09	117 11 27	1091.00	4/28/1931	2/19/1993	25	
S445	10262500	MOJAVE R A BARSTOW CA	YES	34 54 25	117 01 19	1290.00	4/14/1905	1/11/2005	72	2,090' Above Sea Level NGVD29
S446	10262600	BOOM C NR BARSTOW CA		34 54 20	116 56 55	0.24	9/13/1959	10/20/2004	40	2,270' Above Sea Level NGVD29
S447	10263000	MOJAVE R A AFTON CA		35 02 14	116 23 00	2121.00	3/16/1930	1/12/2005	55	1,398.15' Above Sea Level NGVD29
S448	10263100	ZZYZX C NR BAKER CA		35 11 40	116 09 05	0.23	5/12/1905	5/22/1905	11	
S449	102512597	Amargosa River near Death Valley Junction, CA		36 18 30	116 24 09		2/23/1998	2/23/1998		
S450	S6402D	Twenty Nine Palms Ch @ Amboy Rd					3/21/1979	9/30/2007		
S451	S6451B	Yucca @ Sage					6/1/1968	9/30/1989		
S452	S6453A	Quail Canyon					2/22/1973			
S453	S64541A	Old Woman Springs Channel					4/20/1998			
S454	2936	Desert Knolls Wash					9/22/2003			
S455	2951	Antelope Creek Wash					6/14/2004			
S456	2925	Oro Grande					7/2/2003			
S457	S4401A	D St Storm Drain @ E St					7/12/1978	12/13/1979		
S458	S4501B	S.W. Barstow Ch @ Main St					7/12/1978	3/1/1991		
S459	S6201A	Mojave Dry Ch @ Mojave Dr					7/12/1978	2/26/1991		
S460	S6301A	Lucerne Valley Storm Drain					7/12/1978	2/26/1991		
S461	S6402B	Donnel Basin					6/21/1967			

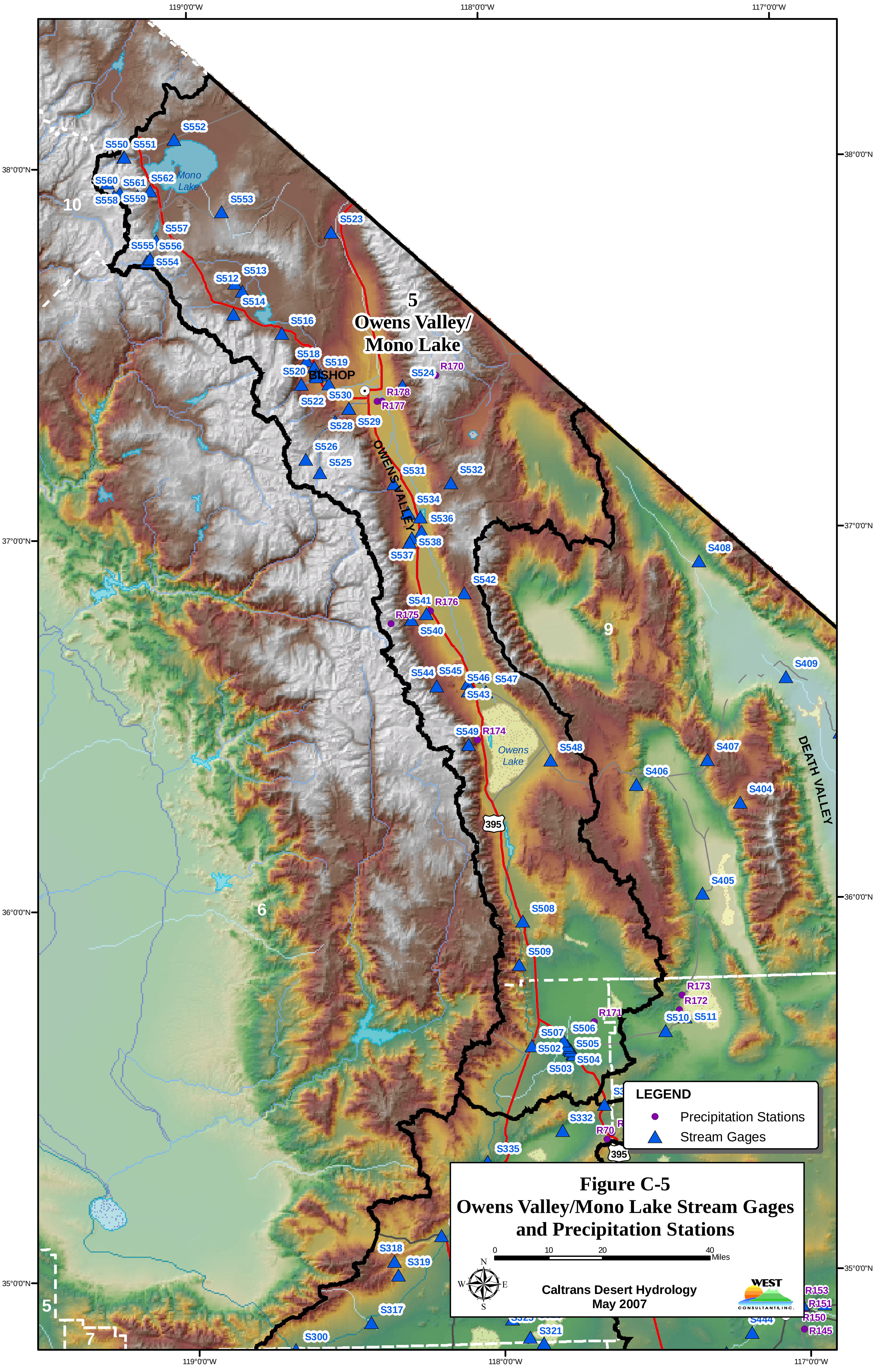

Figure C-5
Owens Valley/Mono Lake Stream Gages and Precipitation Stations

Caltrans Desert Hydrology
May 2007

Owens Valley/Mono Lake - Region 5, Peak Flow Gages

ID	Station #	Station Name	Regulated	Latitude (Deg, Min, Sec)	Longitude (Deg, Min, Sec)	Drainage Area (sq mi)	Beginning of Peak Flow data	End of Peak Flow Data	Years of Record	Elevation at Gaging Station (Feet above sea level)
S500	10264780	EL PASO WASH NR INYOKERN CA		35 35 58	117 45 20	34.60	9/29/1976	2/10/1978	3	2,527' Above Sea Level NGVD29
S501	10264785	EL PASO WASH TRIB NO 5 NR INYOKERN CA		35 35 49	117 45 09	0.25	9/29/1976	3/4/1978	3	2,540' Above Sea Level NGVD29
S502	10264790	EL PASO WASH TRIB NO 3 NR INYOKERN CA		35 36 40	117 45 54	1.67	9/29/1976	3/4/1978	3	2,506' Above Sea Level NGVD29
S503	10264795	EL PASO WASH TRIB NO 4 NR INYOKERN CA		35 36 27	117 45 39	0.37	9/29/1976	2/10/1978	3	2,514' Above Sea Level NGVD29
S504	10264800	EL PASO WASH TRIB NO 2 NR INYOKERN CA		35 37 05	117 46 16	0.42	9/29/1976	2/10/1978	3	2,491' Above Sea Level NGVD29
S505	10264810	EL PASO WASH TRIB NO 1 NR INYOKERN CA		35 37 19	117 46 27	0.48	9/29/1976	2/10/1978	3	2,478' Above Sea Level NGVD29
S506	10264820	LITTLE DIXIE WASH NR INYOKERN CA		35 38 04	117 47 06	213.00	9/9/1975	2/10/1978	4	
S507	10264840	SAND C NR INYOKERN CA		35 37 25	117 53 25	0.95	2/16/1959	2/11/1973	15	2,990' Above Sea Level NGVD29
S508	10264870	LITTLE LAKE C NR LITTLE LAKE CA		35 57 33	117 54 44	8.29	8/4/1964	2/11/1973	8	3,250' Above Sea Level NGVD29
S509	10264878	NINEMILE C NR BROWN CA		35 50 35	117 55 35	10.40	2/9/1962	1976	15	
S510	10264900	SALT WELLS C NR WESTEND CA		35 39 20	117 26 50	61.60	2/16/1959	2/11/1973	15	1,860' Above Sea Level NGVD29
S511	10264915	CRUST C NR WESTEND CA		34 41 25	117 22 50	0.13	9/13/1959	2/11/1973	14	
S512	10265150	HOT C A FLUME NR MAMMOTH LAKES CA		37 40 08	118 49 00	68.30	6/11/1990	6/16/2005	16	6,950' Above Sea Level NGVD29
S513	10265160	LITTLE HOT C BL HOT SPR NR MAMMOTH LAKES, CA		37 41 25	118 50 31	0.00	7/30/1991	4/11/1995	5	6,990' Above Sea Level NGVD29
S514	10265200	CONVICT C NR MAMMOTH LAKES CA		37 36 26	118 50 52	18.20	5/21/1926	7/16/1978	53	
S515	10265500	OWENS R NR ROUND VALLEY CA	YES	37 26 25	118 33 20	425.00	6/16/1904	6/18/1940	33	4,400' Above Sea Level NGVD29
S516	10265700	ROCK C A LITTLE ROUND VALLEY NR BISHOP CA		37 33 15	118 41 03	35.80	6/14/1927	6/9/1978	52	7,280' Above Sea Level NGVD29
S517	10266000	ROCK C AT SHERWIN HILL NR BISHOP CA	YES	37 28 45	118 36 05	51.70	7/5/1923	6/18/1940	18	4,900' Above Sea Level NGVD29
S518	10266200	PARADISE C NR PARADISE CAMP CA		37 27 45	118 34 35	4.75	2/1/1963	1973	11	
S519	10266500	ROCK C NR ROUND VALLEY CA	YES	37 26 25	118 34 15	96.00	6/16/1904	6/18/1940	31	4,450' Above Sea Level NGVD29
S520	10267000	PINE C A DIVISION BOX NR BISHOP CA		37 24 59	118 37 15	36.40	6/26/1922	5/27/1979	58	5,280' Above Sea Level NGVD29
S521	10267500	PINE C NR ROUND VALLEY CA		37 26 10	118 34 10	37.00	6/3/1904	6/13/1940	29	4,450' Above Sea Level NGVD29
S522	10268000	OWENS R A PLEASANT VALLEY NR BISHOP CA		37 25 00	118 31 40	596.00	5/30/1919	6/17/1940	22	4,350' Above Sea Level NGVD29
S523	10268630	BLIND C NR BENTON CA		37 49 30	118 30 42	1.93	1964	6/15/1969	6	
S524	10268700	SILVER CYN C NR LAWS CA		37 24 28	118 16 43	20.00	4/14/1930	6/22/1978	49	5,120' Above Sea Level NGVD29
S525	10270800	SF BISHOP C BL S LK NR BISHOP CA	YES	37 10 38	118 33 44	13.40	9/28/1991	7/23/2005	15	9,580' Above Sea Level NGVD29
S526	10270872	MF BISHOP C BL LK SABRINA NR BISHOP CA	YES	37 12 50	118 36 34	16.70	7/15/1991	7/23/2005	15	9,060' Above Sea Level NGVD29
S527	10270960	COYOTE C NR BISHOP CA	YES	37 18 54	118 30 33	25.70	5/6/1991	4/26/1996	6	5,560' Above Sea Level NGVD29
S528	10271200	BISHOP C AB PP NO 6 NR BISHOP CA	YES	37 21 00	118 27 42	104.00	3/27/1991	7/19/2005	15	
S529	10271210	BISHOP C BL PP NO 6 NR BISHOP CA (ACTUAL) CA	YES	37 20 59	118 27 41	104.00	8/10/1983	10/26/1986	5	
S530	10272000	BISHOP C NR BISHOP CA		37 21 00	118 27 40	104.00	6/16/1904	7/22/1910	7	
S531	10276000	BIG PINE C NR BIG PINE CA		37 08 42	118 18 52	39.00	7/15/1908	9/5/1978	62	
S532	10276200	DEADMAN C NR BIG PINE CA		37 08 40	118 07 15	2.38	1964	2/11/1973	10	
S533	10276500	TINEMAHA C NR BIG PINE CA		37 03 50	118 16 00	27.30	7/4/1907	7/18/1910	4	
S534	10277000	BIRCH C NR BIG PINE CA		37 04 02	118 16 09	10.80	7/4/1907	7/18/1910	4	
S535	10277400	OWENS R BL TINEMAHA RE NR BIG PINE CA	YES	37 03 11	118 13 35	1964.00	8/24/1983	8/24/1983	1	1,964' Above Sea Level NGVD29
S536	10277500	OWENS R NR BIG PINE CA		37 00 55	118 13 25	1976.00	7/29/1906	4/21/1974	69	3,800' Above Sea Level NGVD29
S537	10278000	TABOOSE C NR ABERDEEN CA		36 59 54	-118.2570	11.50	7/14/1906	5/30/1910	5	
S538	10278500	GOODALE C NR ABERDEEN CA		36 59 10	118 15 50	11.20	7/7/1906	5/31/1910	5	
S539	10281500	OAK C NR INDEPENDENCE CA		36 50 00	118 14 35	26.90	7/7/1906	7/18/1910	5	
S540	10281800	INDEPENDENCE C BL PINYON C NR INDEPENDENCE CA		36 46 43	118 15 49	18.10	7/3/1923	7/27/1978	56	
S541	10282000	INDEPENDENCE C NR INDEPENDENCE CA		36 47 35	118 12 45	18.80	7/9/1906	7/18/1910	5	4,134' Above Sea Level NGVD29
S542	10282480	MAZOURKA C NR INDEPENDENCE CA		36 50 50	118 05 02	26.70	1961	1972	12	
S543	10284500	OWENS R NR LONE PINE CA		36 37 10	118 02 05	2534.00	7/7/1909	6/25/1918	10	3,650' Above Sea Level NGVD29
S544	10284800	INYO C NR LONE PINE CA		36 35 52	118 10 58	1.71	8/8/1963	1/14/1973	11	5,840' Above Sea Level NGVD29
S545	10285000	LONE PINE C NR LONE PINE CA		36 36 10	118 04 40	32.10	7/25/1906	5/30/1910	5	3,937' Above Sea Level NGVD29
S546	10285500	TUTTLE C NR LONE PINE CA		36 35 00	118 04 40	14.70	7/25/1906	12/7/1909	5	3,970' Above Sea Level NGVD29
S547	10285700	OWENS R A KEELER BRIDGE NR LONE PINE CA	YES	36 34 46	118 01 06	2604.00	7/20/1927	6/4/1979	53	3,600' Above Sea Level NGVD29
S548	10285780	OWENS LK TRIB NR KEELER CA		36 23 30	117 48 23	3.83	8/16/1965	11/14/1972	9	4,270' Above Sea Level NGVD29
S549	10286000	COTTONWOOD C NR OLANCHA CA		36 26 20	118 04 48	40.10	6/13/1906	9/10/1976	68	
S550	10287069	MILL C BL LUNDY LK NR LEE VINING CA	YES	38 01 59	119 12 56	17.10	7/19/1991	6/16/2005	12	7,760' Above Sea Level NGVD29
S551	10287070	MILL C BL LUNDY LK NR MONO LK(ACTUAL) CA	YES	38 01 58	119 12 53	17.10	6/22/1983	5/30/1987	5	
S552	10287210	BRIDGEPORT C NR BODIE CA		38 04 45	119 02 40	13.10	1/31/1963	1973	11	
S553	10287240	DRY C NR JUNE LAKE CA		37 53 00	118 53 05	2.33	1964	1969	6	
S554	10287281	RUSH C BL GEM LK NR JUNE LK CA	YES	37 45 05	119 08 26	22.00	5/21/2001	7/16/2005	5	9,000' Above Sea Level NGVD29
S555	10287289	RUSH C BL AGNEW LK NR JUNE LAKE CA	YES	37 45 33	119 07 47	23.30	10/31/1990	7/12/2005	13	8,440' Above Sea Level NGVD29
S556	10287290	RUSH C BL AGNEW LK NR JUNE LAKE CA (ACTUAL) CA	YES	37 45 32	119 07 47	23.30	8/1/1983	10/1/1986	5	8,480' Above Sea Level NGVD29
S557	10287400	RUSH C AB GRANT LK NR JUNE LK CA	YES	37 48 23	119 06 29	51.30	5/29/1937	5/28/1979	42	7,200' Above Sea Level NGVD29
S558	10287655	LEE VINING C BL SADDLEBAG LK NR LEE VINING CA	YES	37 57 52	119 16 20	4.43	3/23/1998	8/24/2005	8	4.43' Above Sea Level NGVD29
S559	10287720	GLACIER C BL TIOGA LK NR LEE VINING CA	YES	37 55 41	119 15 01	3.67	6/24/1998	6/24/1998	1	9,620' Above Sea Level NGVD29
S560	10287770	LEE VINING C BL RHINEDOLLAR DAM NR LEE VINING CA	YES	37 56 10	119 13 48	16.70	6/12/1991	6/15/2005	15	9,450' Above Sea Level NGVD29
S561	10287900	LEE VINING C NR LEE VINING CA	YES	37 55 46	119 10 10	34.90	6/7/1935	6/6/1979	45	7,400' Above Sea Level NGVD29
S562	10288000	LEE VINING C NR MONO LK CA		37 56 30	119 07 40	40.60	6/19/1911	6/20/1914	4	

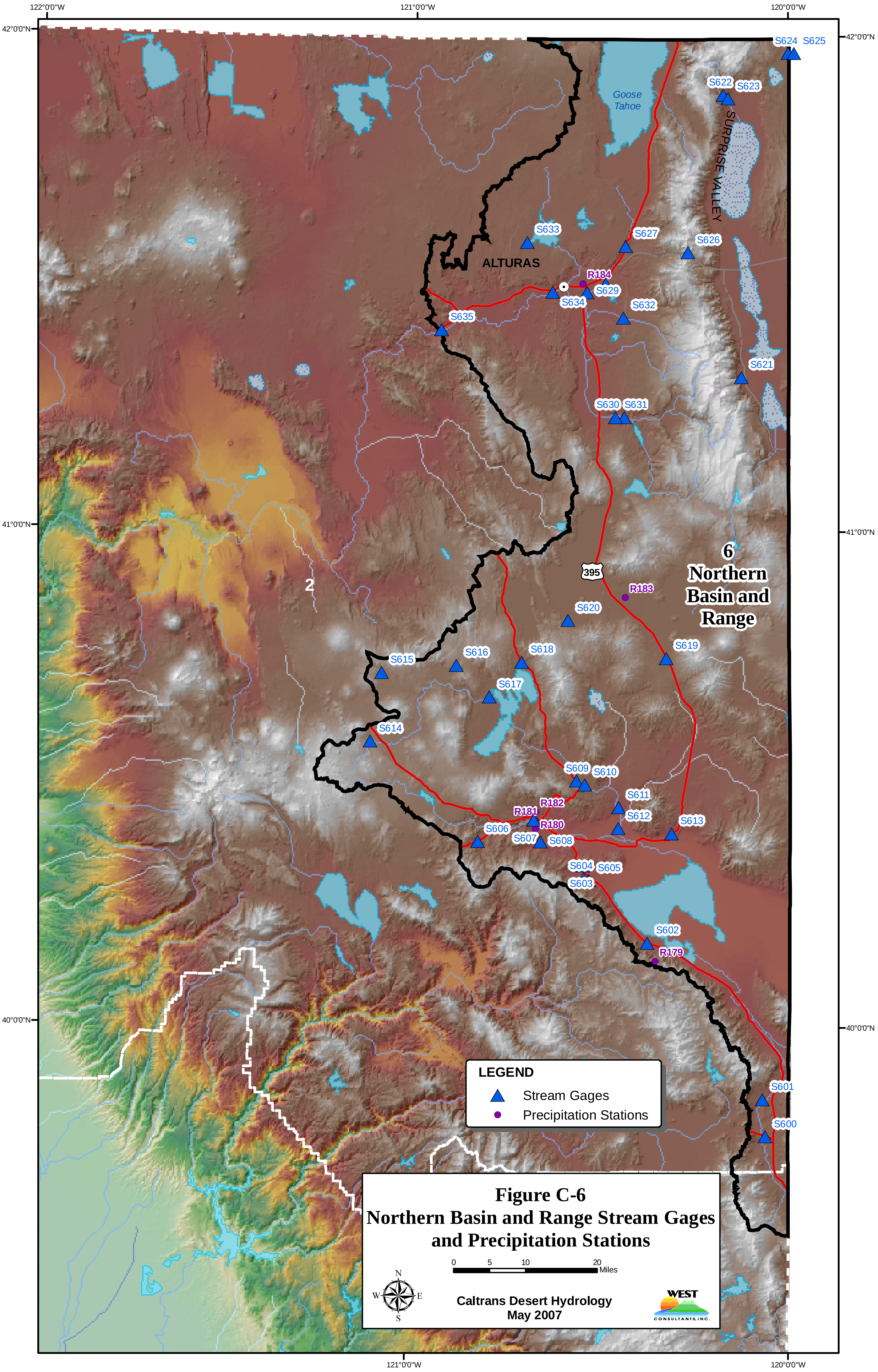

Figure C-6
Northern Basin and Range Stream Gages and Precipitation Stations

Caltrans Desert Hydrology
May 2007

Northern Basin and Range - Region 6, Peak Flow Gages

ID	Station #	Station Name	Regulated	Latitude (Deg, Min, Sec)	Longitude (Deg, Min, Sec)	Drainage Area (sq mi)	Beginning of Peak Flow data	End of Peak Flow Data	Years of Record	Elevation at Gaging Station (Feet above sea level)
S600	10353985	WASHOE C NR HALLELUJAH JUNCTION CA		39 46 50	120 03 35	1.53	1964	1/16/1973	8	
S601	10354000	LONG VALLEY C NR SCOTTS CA		39 51 20	120 04 00	125.00	4/4/1917	1994	7	4,620' Above Sea Level NGVD29
S602	10354700	MILL C A MILFORD CA		40 10 15	120 22 14	2.26	1964	1/16/1973	10	
S603	10355000	BAXTER C NR JANESVILLE CA		40 19034	120 32 24	19.60	1/25/1914	3/1/1919	4	
S604	10355500	SCHLOSS C A JANESVILLE CA		40 18 00	120 32 20	1.05	5/11/1915	4/30/1919	3	
S605	10356000	BANKHEAD C A JANESVILLE CA		40 17 46	120 31 27	1.83	5/11/1915	2/10/1919	3	4,230' Above Sea Level NGVD29
S606	10356300	WF WILLARD C TRIB NR WESTWOOD CA		40 22 25	120 49 05	0.83	1/31/1963	1/16/1973	11	
S607	10356500	SUSAN R A SUSANVILLE CA	YES	40 25 03	120 40 15	184.00	2/23/1901	1/2/1997	54	
S608	10357000	GOLD RUN C AB RICHMOND SCHOOL NR SUSANVILLE CA		40 22 25	120 39 10	15.70	2/24/1958	5/22/1967	10	
S609	10358470	WILLOW C TRIB NR SUSANVILLE CA		40 29 48	120 33 30	3.08	2/1/1963	2/12/1973	11	
S610	10358500	WILLOW C NR SUSANVILLE CA		40 29 21	120 32 10	90.00	1/23/1951	1/2/1997	44	
S611	10358700	WILLOW C NR LITCHFIELD CA		40 26 36	120 26 48	252.00	2/25/1958	3/16/1967	9	4,120' Above Sea Level NGVD29
S612	10359000	WILLOW C NR STANDISH CA		40 24 05	120 26 50	633.00	1/23/1905	1/23/1905	1	4,060' Above Sea Level NGVD29
S613	10359100	SHAFFER C NR LITCHFIELD CA		40 23 30	120 18 23	5.63	1964	1/18/1973	10	
S614	10359250	PINE C NR WESTWOOD CA		40 34 26	121 06 18	24.80	10/30/1950	3/5/1978	22	
S615	10359270	ASPEN C NR WESTWOOD CA		40 42 47	121 04 36	4.70	1/23/1970	1/12/1980	11	
S616	10359290	PINE C TRIB NR SUSANVILLE CA		40 43 44	120 52 44	4.70	3/26/1971	1/12/1980	10	
S617	10359300	PINE C NR SUSANVILLE CA		40 39 54	120 47 25	226.00	4/5/1961	4/12/1982	22	
S618	10359350	EAGLE LK TRIB NR SUSANVILLE CA		40 44 10	120 42 20	0.91	2/1/1963	2/10/1973	11	
S619	10359490	MADELINE PLAINS TRIB NR RAVENDALE CA				0.06	10/13/1962	2/27/1973	9	
S620	10359510	WHISKEY C NR TERMO CA				4.56	2/1/1963	4/10/1973	11	
S621	10360230	EAGLE C A EAGLEVILLE CA		41 18 45	120 07 27	6.36	5/28/1962	6/6/1970	8	
S622	10360900	BIDWELL C BL MILL C NR FORT BIDWELL CA		41 52 57	120 10 26	25.60	5/20/1961	12/20/1981	22	4,935' Above Sea Level NGVD29
S623	10361000	BIDWELL C A FORT BIDWELL CA		41 52 30	120 09 40	27.00	6/1/1912	4/30/1919	3	
S624	10363500	KEENO C NR FORT BIDWELL CA		41 58 00	120 00 00	6.00	3/18/1918	4/2/1919	2	5,500' Above Sea Level NGVD29
S625	10364000	ROCK C NR FORT BIDWELL CA				19.00	3/25/1918	4/2/1919	2	
S626	11342945	THOMS C NR CEDARVILLE CA		41 33 50	120 16 05	1.06	1/31/1963	4/17/1973	11	
S627	11342960	NF PIT R TRIB NR ALTURAS CA		41 34 35	120 26 05	2.36	10/12/1962	12/18/1972	11	
S628	11343500	NF PIT R NR ALTURAS CA		41 30 00	120 29 18	203.00	2/7/1930	1/29/1967	12	4,391' Above Sea Level NGVD29
S629	11344000	NF PIT R A ALTURAS CA		41 28 56	120 32 16	212.00	2/29/1972	3/31/1985	13	
S630	11345500	SF PIT R NR LIKELY CA		41 13 51	120 26 10	247.00	4/27/1932	5/6/2005	74	4,508' Above Sea Level NGVD29
S631	11345800	SF PIT R TRIB NR LIKELY CA		41 13 51	120 27 35	1.59	12/28/1964	3/15/1973	9	
S632	11347500	PINE C NR ALTURAS CA	YES	41 25 54	120 26 22	23.50	3/29/1919	5/12/1931	13	4,700' Above Sea Level NGVD29
S633	11348080	BIG SAGE RES TRIB NR ALTURAS CA		41 35 00	120 41 55	2.54	10/12/1962	1/16/1973	11	
S634	11348200	PIT R NR ALTURAS CA		41 29 00	120 37 46	1080.00	3/10/1966	6/3/1971	6	
S635	11348500	PIT R NR CANBY CA		41 24 22	120 55 36	1431.00	3/8/1904	5/10/2005	76	4,266' Above Sea Level NGVD29

Precipitation Stations

Label	ID	Name	Region	Latitude	Longitude	Elev (ft)	Begin	End	Source	NOAA_Atlas14
R1	1320	Jacumba	Colorado Desert	32.6170	-116.1830	0	daily only		County of San Diego	
R2	365	Boulevard 2	Colorado Desert	32.6670	-116.3000	0	closed in 1980		County of San Diego	
R3	121	EL CENTRO 2 SSW	Colorado Desert	32.7667	-115.5667	-30	3/1/1932	-	NCDC Hourly Precip Stations	YES
R4	39	CRAWFORD RANCH	Colorado Desert	32.8833	-116.2833	1503	7/1/1948	1/1/1985	NCDC Hourly Precip Stations	YES
R5	30 64	Agua Caliente	Colorado Desert	32.9570	-116.2970	0	1984	-	County of San Diego	
R6	7p	Near Scissors Crossing 0.152 DD SSE	Colorado Desert	33.0300	-116.3100	0	1995	-	County of San Diego	
R7	224	JULIAN	Colorado Desert	33.0833	-116.6000	4216	9/1/1949	11/30/1966	NCDC Hourly Precip Stations	
R8	6p	Creeks No 1782 0.068 DD NNW ID 53	Colorado Desert	33.1500	-116.6100	0			County of San Diego	
R9	270 63	Borrego C.R.S.	Colorado Desert	33.2210	-116.3350	0	1963	-	County of San Diego	
R10	300	Borrego Desert Park	Colorado Desert	33.2670	-116.4170	0	daily only		County of San Diego	
R11	315 62	Borrego Palm Canyon	Colorado Desert	33.2690	-116.4120	0	1969	-	County of San Diego	
R12	61	Coyote Canyon Creek	Colorado Desert	33.3660	-116.4160	0	1984	-	County of San Diego	
R13	2p	NE County Boundary with Riverside County	Colorado Desert	33.4200	-116.2400	0			County of San Diego	
R14	1800	Mecca	Colorado Desert	33.5330	-116.0500	0			County of San Diego	
R15	00-0157	PINYON FLAT	Colorado Desert	33.5856	-116.4472	4000	8/1977	5/2000	NOAA Atlas 14	
R16	289	PALM SPRINGS THERMAL	Colorado Desert	33.6333	-116.1667	-112	5/1/1950	-	NCDC Hourly Precip Stations	
R17	40	THERMAL FIRE STN 39	Colorado Desert	33.6333	-116.1667	-115	11/1/1972	-	NCDC Hourly Precip Stations	YES
R18	87	INDIO COACHELLA	Colorado Desert	33.6833	-116.1667	-66	4/1/1938	5/31/1950	NCDC Hourly Precip Stations	
R19	00-0081	HAYSTACK-MNT	Colorado Desert	33.7022	-116.4789	2800	7/1979	7/1999	NOAA Atlas 14	
R20	00-0034	CATHEDRAL CITY	Colorado Desert	33.7803	-116.4575	295	1/1969	2/1996	NOAA Atlas 14	
R21	00-0222	THOUSAND PALMS	Colorado Desert	33.8200	-116.3928	2409	1/1980	7/2000	NOAA Atlas 14	
R22	00-0216	TACHEVAH DAM	Colorado Desert	33.8319	-116.5578	580	8/1967	7/2000	NOAA Atlas 14	
R23	00-0224	TRAMWAY VALLEY STA	Colorado Desert	33.8369	-116.6125	2700	8/1977	7/2000	NOAA Atlas 14	
R24	04-1250	CABAZON	Colorado Desert	33.9092	-116.7811	1700	6/1975	12/2000	NOAA Atlas 14	
R25	00-0243	WIDE CANYON DAM	Colorado Desert	33.9344	-116.3908	1530	10/1975	1/1997	NOAA Atlas 14	
R26	00-0057	DES HOT SPR EAST	Colorado Desert	33.9675	-116.4944	1220	11/1949	7/2000	NOAA Atlas 14	
R27	00-0011	BANNING BENCH	Colorado Desert	33.9722	-116.9117	3600	6/1974	7/2000	NOAA Atlas 14	
R28	00-0233	WHITEWATER NORTH	Colorado Desert	33.9897	-116.6556	2200	8/1977	7/2000	NOAA Atlas 14	
R29	6000	Morongo Valley Post Office	Colorado Desert	34.0500	-116.5800	2580	4/15/1991	-	San Bernardino County	
R30	6354	Morongo Valley Trailer Park	Colorado Desert	34.0700	-116.5500	2765	6/30/1983	7/1/1992	San Bernardino County	
R31	225	BLYTHE 7 W	Sonoran Desert	33.6167	-114.7167	390	2/1/1953	1/1/1995	NCDC Hourly Precip Stations	YES
R32	290	BLYTHE RIVERSIDE AP	Sonoran Desert	33.6167	-114.7167	390	6/1/1931	-	NCDC Hourly Precip Stations	
R33	88	HAYFIELD PUMP PLANT	Sonoran Desert	33.7000	-115.6333	1371	7/1/1933	-	NCDC Hourly Precip Stations	YES
R34	RVYC1	RICE VALLEY	Sonoran Desert	34.0608	-114.7322	820			San Bernardino County Other Agency	
R35	6004	Big River County Yard	Sonoran Desert	34.1300	-114.3700	400	4/29/1999	-	San Bernardino County	
R36	44	PARKER RESERVOIR	Sonoran Desert	34.2833	-114.1667	738	1/1/0934	-	NCDC Hourly Precip Stations	YES
R37	1062	Buckhorn Flat Precip	Antelope Valley	34.3456	-117.9189	0	discontinued		LA County ALERT Recording Gages	
R38	402F	Cedar Springs Precip	Antelope Valley	34.3558	-117.8761	0	10/29/2001	-	LA County ALERT Recording Gages	
R39	6379	Wrightwood - Apple	Antelope Valley	34.3600	-117.6400	6020	10/2/1980	10/1/1996	San Bernardino County	
R40	6380	Wrightwood - Pine	Antelope Valley	34.3600	-117.6400	6150	10/2/1975	10/1/1996	San Bernardino County	
R41	6033	Wrightwood Fire District	Antelope Valley	34.3600	-117.6300	6038	3/19/1956	-	San Bernardino County	
R42	281	BIG PINES PARK FC83B	Antelope Valley	34.3833	-117.6833	6844	1/1/1931	10/1/1996	NCDC Hourly Precip Stations	YES
R43	154	CAJON WEST SUMMIT	Antelope Valley	34.3833	-117.6000	4780	7/1/1948	-	NCDC Hourly Precip Stations	YES
R44	1060B	Little Rock Sycamore Camp Pcp	Antelope Valley	34.4172	-117.9703	0	4/28/2006	-	LA County ALERT Recording Gages	
R45	517B	Lewis Ranch Precip	Antelope Valley	34.4200	-117.8864	0	2/7/2001	-	LA County ALERT Recording Gages	
R46	6396	Pinon Hills	Antelope Valley	34.4200	-117.6100	1250	4/10/1989	10/1/2000	San Bernardino County	
R47	6205A	Phelan County Fire Station #103	Antelope Valley	34.4300	-117.5900	4150	11/17/1998	10/1/2000	San Bernardino County	
R48	2922	Phelan Landfill	Antelope Valley	34.4400	-117.6100	4099	4/30/2003	-	San Bernardino County	
R49	1248	Mescal Smith Precip	Antelope Valley	34.4675	-117.7111	0	2/9/2001	-	LA County ALERT Recording Gages	
R50	1017B	Little Rock Crk Above Dam Percip	Antelope Valley	34.4781	-118.0233	0	6/2/2006	-	LA County ALERT Recording Gages	
R51	1250	Avek Precip	Antelope Valley	34.5392	-117.9231	0	2/8/2001	-	LA County ALERT Recording Gages	
R52	75	PALMDALE 2 NE	Antelope Valley	34.6000	-118.1000	2582	3/1/1953	12/31/1962	NCDC Hourly Precip Stations	
R53	6227A	El Mirage Airport	Antelope Valley	34.6000	-117.6100	2910	4/17/1964	10/1/1997	San Bernardino County	
R54	77	PALMDALE	Antelope Valley	34.6333	-118.0833	2517	7/1/1929	-	NCDC Hourly Precip Stations	YES
R55	EMRC1	EL MIRAGE	Antelope Valley	34.6344	-117.5489	2880			San Bernardino County Other Agency	
R56	1245	Quartz Hill Precip	Antelope Valley	34.6481	-118.2400	0	10/13/1999	-	LA County ALERT Recording Gages	
R57	1242	Rocky Buttes Precip	Antelope Valley	34.6500	-117.8633	0	10/1/2001	-	LA County ALERT Recording Gages	
R58	1244	Lancaster Roper Ranch Precip	Antelope Valley	34.6797	-118.0103	0	2/7/2001	-	LA County ALERT Recording Gages	
R59	SDLC1	SADDLEBACK BUTTE	Antelope Valley	34.6847	-117.8208	2590			San Bernardino County Other Agency	
R60	23	LANCASTER FOX FLD	Antelope Valley	34.7333	-118.2167	2339	11/1/1959	-	NCDC Hourly Precip Stations	
R61	105	SANDBERG	Antelope Valley	34.7500	-118.7167	4518	4/1/1932	-	NCDC Hourly Precip Stations	
R62	1247	North Lancaster Precip	Antelope Valley	34.7614	-118.1250	0	2/6/2001	-	LA County ALERT Recording Gages	
R63	1249	Relay Precip	Antelope Valley	34.7619	-117.7986	0	2/12/2001	-	LA County ALERT Recording Gages	
R64	1243	Redman Precip	Antelope Valley	34.7644	-117.9250	0	2/8/2001	-	LA County ALERT Recording Gages	
R65	1246	Scott Ranch Precip	Antelope Valley	34.7831	-118.4694	0	2/7/2001	-	LA County ALERT Recording Gages	
R66	KEDW	Edwards Air Force Base	Antelope Valley	34.9167	-117.9000	2303			San Bernardino County Other Agency	
R67	K9L2	Edwards Air Force Auxiliary North Base	Antelope Valley	34.9833	-117.8500	2300			San Bernardino County Other Agency	
R68	80	BORON	Antelope Valley	35.0000	-117.6500	2454	10/1/1959	-	NCDC Hourly Precip Stations	YES
R69	249	MOJAVE	Antelope Valley	35.0500	-118.1667	2736	1/1/1947	-	NCDC Hourly Precip Stations	YES
R70	216	RANDSBURG	Antelope Valley	35.3667	-117.6500	3570	9/1/1937	-	NCDC Hourly Precip Stations	
R71	SQSC1	SQUAW SPRINGS	Antelope Valley	35.3683	-117.5703	3620			San Bernardino County Other Agency	
R72	30	JOHANNESBURG	Antelope Valley	35.3833	-117.6333	3553	7/1/1948	8/31/1949	NCDC Hourly Precip Stations	
R73	6006	Yucca Valley - Alta Loma Tank	Mojave Desert	34.0900	-116.4200	3740	3/27/1996	-	San Bernardino County	
R74	6008	Joshua Tree-Quail Springs	Mojave Desert	34.0900	-116.2700	3568	10/28/2003	-	San Bernardino County	
R75	6102	Yucca Valley C.D.F.	Mojave Desert	34.1200	-116.4100	3420	10/1/1957	-	San Bernardino County	
R76	6336	Dale Lake - Craine	Mojave Desert	34.1200	-115.7700	1315	5/1/1975	10/1/1995	San Bernardino County	
R77	UCCC1	YUCCA VALLEY	Mojave Desert	34.1233	-116.4078	3260			San Bernardino County Other Agency	
R78	6134B	Joshua Tree	Mojave Desert	34.1300	-116.2900	2760	4/1/1953	10/1/1985	San Bernardino County	
R79	6048A	Twentynine Palms	Mojave Desert	34.1300	-116.0400	1975	5/1/1935	-	San Bernardino County	
R80	160	IRON MOUNTAIN	Mojave Desert	34.1333	-115.1333	922	1/1/1935	-	NCDC Hourly Precip Stations	YES
R81	6384	Joshua Tree Water District	Mojave Desert	34.1400	-116.3200	2710	8/25/1988	10/1/1992	San Bernardino County	
R82	6216	Twentynine Palms County Yard	Mojave Desert	34.1500	-116.0500	1895	12/1/1960	-	San Bernardino County	
R83	6245	Dale Dry Lake - Barnett's Trading Post	Mojave Desert	34.1500	-115.7000	1220	12/10/1964	10/1/1978	San Bernardino County	
R84	6401	Wonder Valley	Mojave Desert	34.1600	-115.9300	1250	5/20/1991	10/1/1994	San Bernardino County	
R85	6139	Kee Ranch	Mojave Desert	34.1700	-116.5500	4325	10/2/1950	10/1/1984	San Bernardino County	
R86	6397	Shadow Mountain	Mojave Desert	34.1700	-115.9800	1360	10/2/1989	10/1/1993	San Bernardino County	
R87	6007	Wonder Valley F.S. - East	Mojave Desert	34.1700	-115.7500	1224	8/28/1999	-	San Bernardino County	
R88	33	RUNNING SPRINGS 1 E	Mojave Desert	34.2000	-117.0833	5965	7/1/1948	-	NCDC Hourly Precip Stations	YES
R89	6366	Rimrock	Mojave Desert	34.2000	-116.5600	4520	4/9/1981	10/1/1986	San Bernardino County	
R90	BCNC1	BURNS CANYON	Mojave Desert	34.2083	-116.6208	6000			San Bernardino County Other Agency	
R91	6070	Camp Oakes	Mojave Desert	34.2300	-116.7500	7450	12/18/1962	10/1/1985	San Bernardino County	
R92	4733	Baine Ranch Baker Hill	Mojave Desert	34.2300	-116.6400	2700	10/2/1979	10/1/1983	San Bernardino County	
R93	283	CRESTLINE LAKE GREGO	Mojave Desert	34.2333	-117.2667	4534	10/14/1952	4/18/1966	NCDC Hourly Precip Stations	
R94	256	CRESTLINE	Mojave Desert	34.2500	-117.3000	4872	7/1/1948	10/13/1952	NCDC Hourly Precip Stations	YES
R95	4314	Lake Silverwood State Recreation Park	Mojave Desert	34.2800	-117.3500	3400	11/1/1972	-	San Bernardino County	
R96	4328	Silverwood Dam (Dwr)	Mojave Desert	34.3000	-117.3200	3200	10/2/1973	10/1/1974	San Bernardino County	
R97	6402	Twentynine Palms U.S.M.C.	Mojave Desert	34.3000	-116.1500	2004	10/2/1977	6/1/2001	San Bernardino County	
R98	4169B	Summit Valley - Rentfro	Mojave Desert	34.3100	-117.3500	3280	12/11/1964	9/1/1985	San Bernardino County	
R99	4319	Summit Valley Fire Station	Mojave Desert	34.3100	-117.3300	3250	6/12/1973	10/1/1978	San Bernardino County	
R100	4169	Summit Valley - Las Flores Ranch	Mojave Desert	34.3100	-117.3200	3185	12/21/1956	10/1/1971	San Bernardino County	
R101	2970	Summit Valley	Mojave Desert	34.3300	-117.4000	3313	12/11/2003	-	San Bernardino County	
R102	6005	Cajon Summit	Mojave Desert	34.3500	-117.4400	4160	2/15/1996	10/1/1998	San Bernardino County	
R103	6224	Cushenberry Springs	Mojave Desert	34.3600	-116.8600	4250	7/14/1961	6/1/2001	San Bernardino County	
R104	6255A	Johnson Valley - Mojave Water Agency	Mojave Desert	34.3700	-116.6100	2950	11/13/1997	-	San Bernardino County	
R105	MNLC1	MEANS LAKE	Mojave Desert	34.3844	-116.5239	2900			San Bernardino County Other Agency	
R106	4002	Hesperia Pump Plant #22	Mojave Desert	34.3900	-117.3100	3380	11/2/1994	-	San Bernardino County	
R107	6223	Ivanpah County Yard	Mojave Desert	34.3900	-115.2600	2927	7/1/1961	10/1/1987	San Bernardino County	
R108	2951	Antelope Creek Wash	Mojave Desert	34.4000	-117.2800	3103	6/14/2004	-	San Bernardino County	
R109	4003	Apple Valley-Rock Springs Turnout	Mojave Desert	34.4100	-117.2300	2890	12/19/1994	-	San Bernardino County	
R110	6205	Phelan C.D.F.	Mojave Desert	34.4200	-117.5700	4160	6/20/1956	10/1/1999	San Bernardino County	
R111	4195	Hesperia C.D.F.	Mojave Desert	34.4200	-117.3000	3175	2/21/1956	10/1/1999	San Bernardino County	
R112	6255	Johnson Valley - W. C. Shehorn	Mojave Desert	34.4200	-116.6100	2794	10/2/1960	10/1/1997	San Bernardino County	
R113	6001	Lucerne Valley Cemetery	Mojave Desert	34.4400	-116.9500	2946	2/6/1992	-	San Bernardino County	
R114	6057B	Lucerne Valley	Mojave Desert	34.4400	-116.9400	2957	10/2/1948	10/1/1974	San Bernardino County	
R115	6324	Lucerne Valley Fire District	Mojave Desert	34.4400	-116.9400	2957	5/1/1974	10/1/1989	San Bernardino County	
R116	6372	Lucerne Valley Midway Park	Mojave Desert	34.4600	-116.9000	2910	9/24/1981	10/1/1993	San Bernardino County	

Precipitation Stations

Label	ID	Name	Region	Latitude	Longitude	Elev (ft)	Begin	End	Source	NOAA_Atlas14
R117	6383	Baldy Mesa County Yard #1	Mojave Desert	34.4700	-117.3900	3320	2/6/1990	-	San Bernardino County	
R118	4325	Apple Valley County Yard	Mojave Desert	34.4700	-117.1500	3080	1/1/1974	-	San Bernardino County	
R119	6300	Amboy - Saltus #2	Mojave Desert	34.4800	-115.7400	595	6/27/1972	10/1/1993	San Bernardino County	
R120	6382	Victorville - Dale	Mojave Desert	34.4900	-117.3500	3110	9/16/1987	10/1/1994	San Bernardino County	
R121	4136	Apple Valley	Mojave Desert	34.5200	-117.2200	2930	6/1/1956	10/1/1988	San Bernardino County	
R122	2925	Oro Grande	Mojave Desert	34.5300	-117.3000	2798	7/2/2003	-	San Bernardino County	
R123	6298	Amboy - Saltus #1	Mojave Desert	34.5300	-115.7000	625	10/2/1966	10/1/1989	San Bernardino County	
R124	218	VICTORVILLE PUMP PLT	Mojave Desert	34.5333	-117.3000	2858	11/1/1938	-	NCDC Hourly Precip Stations	YES
R125	2936	Desert Knolls Wash	Mojave Desert	34.5400	-117.2700	2808	9/22/2003	-	San Bernardino County	
R126	6381	Desert Knolls	Mojave Desert	34.5500	-117.2400	2980	9/23/1987	10/1/1992	San Bernardino County	
R127	41	AMBOY	Mojave Desert	34.5667	-115.7500	640	7/1/1948	11/13/1974	NCDC Hourly Precip Stations	YES
R128	6391	Adelanto City Water Dept.	Mojave Desert	34.5700	-117.4100	2880	12/22/1988	2/1/2004	San Bernardino County	
R129	4392	Apple Valley Airport	Mojave Desert	34.5700	-117.1900	3058	3/23/1989	-	San Bernardino County	
R130	6089A	Adelanto - Ebert	Mojave Desert	34.5800	-117.4200	2850	3/8/1949	10/1/1989	San Bernardino County	
R131	2926	Victorville L/F	Mojave Desert	34.5900	-117.2700	2959	6/18/2003	-	San Bernardino County	
R132	GNTC1	APPLE VALLEY	Mojave Desert	34.5925	-117.1683	3162			San Bernardino County Other Agency	
R133	4351	Victor Valley Sewage Treatment Plant	Mojave Desert	34.6200	-117.3600	2600	5/12/1983	10/1/1993	San Bernardino County	
R134	6059	Needles Pumping Plant	Mojave Desert	34.6900	-114.6100	1400	5/17/1962	10/1/1989	San Bernardino County	
R135	6375	Ludlow	Mojave Desert	34.7200	-116.1600	1740	8/2/1982	10/1/1985	San Bernardino County	
R136	6002	Essex Cal Trans Yard	Mojave Desert	34.7300	-115.2500	1720	10/31/1994	-	San Bernardino County	
R137	6333	Park Moabi Regional Park	Mojave Desert	34.7300	-114.5100	540	2/18/1975	-	San Bernardino County	
R138	6225	Stoddard Valley	Mojave Desert	34.7500	-117.0000	2840	7/19/1961	2/1/2004	San Bernardino County	
R139	6110	Needles F.A.A.	Mojave Desert	34.7600	-114.6200	914	10/2/1938	10/1/1990	San Bernardino County	
R140	KEED	Needles Airport	Mojave Desert	34.7661	-114.6233	984			San Bernardino County Other Agency	
R141	197	NEEDLES AIRPORT	Mojave Desert	34.7667	-114.6167	915	3/10/1942	-	NCDC Hourly Precip Stations	
R142	6352	Newberry Springs	Mojave Desert	34.8300	-116.6700	1836	5/12/1983	10/1/1985	San Bernardino County	
R143	6178	Needles County Highway Yard	Mojave Desert	34.8300	-114.6000	451	9/1/1957	10/1/1979	San Bernardino County	
R144	43	NEEDLES	Mojave Desert	34.8333	-114.6000	479	1/1/1917	-	NCDC Hourly Precip Stations	YES
R145	2916	Barstow Landfill	Mojave Desert	34.8400	-117.0200	2906	5/21/2003	-	San Bernardino County	
R146	4113	Daggett F.A.A.	Mojave Desert	34.8500	-116.8000	1922	10/2/1946	10/1/1990	San Bernardino County	
R147	4153	Daggett Edison Plant	Mojave Desert	34.8600	-116.8500	1975	10/2/1956	10/1/1993	San Bernardino County	YES
R148	4393	Barstow - Daggett Airport	Mojave Desert	34.8600	-116.7900	1927	4/12/1989	-	San Bernardino County	
R149	158	DAGGETT	Mojave Desert	34.8667	-116.8500	1972	3/1/1953	-	NCDC Hourly Precip Stations	
R150	4322	Barstow - Gaudian	Mojave Desert	34.8900	-117.0400	2140	12/1/1973	10/1/1989	San Bernardino County	
R151	4111A	Barstow Fire District	Mojave Desert	34.8900	-117.0200	2460	10/2/1987	5/1/2001	San Bernardino County	
R152	4233	Yermo Inspection Station	Mojave Desert	34.9100	-116.7900	1912	5/16/1962	-	San Bernardino County	
R153	4219	Barstow County Yard	Mojave Desert	34.9200	-117.0300	2120	11/11/1960	-	San Bernardino County	
R154	6179	Goffs	Mojave Desert	34.9200	-115.0600	2587	5/17/1962	10/1/1968	San Bernardino County	
R155	6215	Mitchell Caverns	Mojave Desert	34.9400	-115.5100	4330	3/1/1948	2/1/2004	San Bernardino County	
R156	6304	Calico County Regional Park	Mojave Desert	34.9500	-116.8600	2340	10/4/1972	-	San Bernardino County	
R157	6228	Kramer Junction - Beechers Corner	Mojave Desert	34.9900	-117.5400	2477	1/16/1962	-	San Bernardino County	
R158	6193	Kelso (Soda Lake Valley)	Mojave Desert	35.0100	-115.6500	2148	5/16/1962	10/1/1991	San Bernardino County	
R159	MRSC1	MOJAVE RIVER SINK	Mojave Desert	35.0531	-116.0794	950			San Bernardino County Other Agency	
R160	MDHC1	MID HILLS	Mojave Desert	35.1231	-115.4114	5413			San Bernardino County Other Agency	
R161	OPLC1	OPAL MOUNTAIN	Mojave Desert	35.1542	-117.1756	3240			San Bernardino County Other Agency	
R162	6398	New York Mountains	Mojave Desert	35.2400	-115.1300	4620	5/1/1990	12/1/2003	San Bernardino County	
R163	159	BAKER	Mojave Desert	35.2667	-116.0667	942	4/1/1931	-	NCDC Hourly Precip Stations	YES
R164	6321	Goldstone Echo	Mojave Desert	35.3000	-116.8100	3220	1/1/1965	10/1/2002	San Bernardino County	
R165	260	SILVER LAKE CAA AP	Mojave Desert	35.3333	-116.0833	922	4/1/1931	11/31/1953	NCDC Hourly Precip Stations	
R166	4108	Silver Lake Airport	Mojave Desert	35.3500	-116.0900	910	10/1/1946	11/1/1953	San Bernardino County	
R167	6109	Yucca Grove	Mojave Desert	35.4000	-115.7900	3951	1/1/1932	10/1/1955	San Bernardino County	
R168	6063	Mountain Pass	Mojave Desert	35.4700	-115.5400	4730	2/1/1955	10/1/1983	San Bernardino County	
R169	HTSC1	HORSE THIEF SPRINGS	Mojave Desert	35.7706	-115.9092	5000			San Bernardino County Other Agency	
R170	180	DEEP SPRINGS 11 NW	Mojave Desert	37.4333	-118.1667	10509	7/1/1948	10/31/1954	NCDC Hourly Precip Stations	
R171	28	CHINA LAKE ARMITAGE	Mono Lake/Owens Valley	35.6833	-117.6833	2238	11/1/1939	-	NCDC Hourly Precip Stations	
R172	6230	Trona County Yard	Mono Lake/Owens Valley	35.7100	-117.4000	1640	8/1/1982	2/1/2004	San Bernardino County	
R173	6111	Trona	Mono Lake/Owens Valley	35.7500	-117.3900	1695	1/1/1920	10/1/1990	San Bernardino County	
R174	181	LONE PINE COTTNWD PH	Mono Lake/Owens Valley	36.4500	-118.0500	3790	7/1/1948	-	NCDC Hourly Precip Stations	
R175	112	INDEPENDENCE ONION V	Mono Lake/Owens Valley	36.7667	-118.3333	9187	12/1/1948	2/25/1971	NCDC Hourly Precip Stations	
R176	148	INDEPENDENCE	Mono Lake/Owens Valley	36.8000	-118.2000	3950	12/1/1894	-	NCDC Hourly Precip Stations	YES
R177	72	BISHOP	Mono Lake/Owens Valley	37.3667	-118.3667	4108	11/21/1996	1/25/2005	NCDC Hourly Precip Stations	
R178	73	BISHOP AP	Mono Lake/Owens Valley	37.3667	-118.3500	4101	8/1/1930	-	NCDC Hourly Precip Stations	YES
R179	134	MILFORD	Northern Basin and Range	40.1333	-120.3500	4859	7/1/1948	-	NCDC Hourly Precip Stations	YES
R180	269	SUSANVILLE STATE RNG	Northern Basin and Range	40.4000	-120.6667	4193	6/4/1949	5/30/1952	NCDC Hourly Precip Stations	
R181	133	SUSANVILLE	Northern Basin and Range	40.4167	-120.6667	4183	1/1/1931	12/16/1946	NCDC Hourly Precip Stations	
R182	230	SUSANVILLE 1 WNW	Northern Basin and Range	40.4333	-120.6667	4554	5/1/1952	-	NCDC Hourly Precip Stations	YES
R183	205	TERMO 1 E	Northern Basin and Range	40.8667	-120.4333	5299	7/1/1948	5/11/1999	NCDC Hourly Precip Stations	YES
R184	270	ALTURAS	Northern Basin and Range	41.5000	-120.5500	4400	5/1/1931	-	NCDC Hourly Precip Stations	YES

APPENDIX D

HEC-SSP Output

USGS Station 10265200 FFA Results

```
-------------------------------
Bulletin 17B Frequency Analysis
    06 Apr 2007   10:51 AM
-------------------------------


--- Input Data ---

Analysis Name: 10265200
Description:

Data Set Name: CONVICT C-MAMMOTH LAKES CA-FLOW-ANNUAL PEAK
DSS File Name: C:\Caltrans\Hydrology\Desert_Hydrology.dss
DSS Pathname: /CONVICT C/MAMMOTH LAKES CA/FLOW-ANNUAL
PEAK/01jan1900/IR-CENTURY/USGS/

Report File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10265200\10265200.rpt
XML File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10265200\10265200.xml

Skew Option: Use Regional Skew
Regional Skew: 0.1
Regional Skew MSE: 0.302
Round adopted skew to nearest tenth

Plotting Position Type: Weibull

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use non-standard frequencies
Frequency: 0.2
Frequency: 0.5
Frequency: 1.0
Frequency: 2.0
Frequency: 4.0
Frequency: 10.0
Frequency: 20.0
Frequency: 50.0
Frequency: 80.0
Frequency: 90.0
Frequency: 95.0
Frequency: 99.0

Round ordinate values to 3 significant digits
Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---


--- Final Results ---

<< Plotting Positions >>
CONVICT C-MAMMOTH LAKES CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|     Events Analyzed      |          Ordered Events          |
```

```
|                    FLOW  |       Water       FLOW  Weibull  |
| Day Mon Year        CFS  |  Rank  Year        CFS  Plot Pos |
|--------------------------|----------------------------------|
|  21 May 1926         95  |    1   1932        290    1.85   |
|  17 Jun 1927        172  |    2   1967        270    3.70   |
|  29 May 1928        114  |    3   1938        231    5.56   |
|  30 Jun 1929         77  |    4   1963        223    7.41   |
|  15 Jun 1930        101  |    5   1969        206    9.26   |
|  21 Oct 1930         50  |    6   1958        201   11.11   |
|  29 Jun 1932        290  |    7   1927        172   12.96   |
|  17 Jun 1933         96  |    8   1956        168   14.81   |
|  16 May 1934         44  |    9   1975        167   16.67   |
|  13 Jun 1935        108  |   10   1962        157   18.52   |
|  25 Jun 1936        131  |   11   1937        156   20.37   |
|  23 Jun 1937        156  |   12   1978        150   22.22   |
|  28 Jun 1938        231  |   13   1945        148   24.07   |
|  02 Jun 1939         55  |   14   1941        145   25.93   |
|  18 Jun 1940        110  |   15   1974        140   27.78   |
|  17 Jun 1941        145  |   16   1957        136   29.63   |
|  07 Jul 1942        134  |   17   1942        134   31.48   |
|  30 May 1943        100  |   18   1936        131   33.33   |
|  03 Jul 1944         82  |   19   1955        126   35.19   |
|  22 Jun 1945        148  |   20   1973        123   37.04   |
|  06 Jun 1946         87  |   21   1965        122   38.89   |
|  26 May 1947         75  |   22   1952        117   40.74   |
|  29 Jun 1948         75  |   23   1928        114   42.59   |
|  12 Jun 1949        110  |   24   1949        110   44.44   |
|  04 Jun 1950         81  |   25   1940        110   46.30   |
|  27 Jun 1951         82  |   26   1935        108   48.15   |
|  09 Jun 1952        117  |   27   1930        101   50.00   |
|  10 Jul 1953         83  |   28   1943        100   51.85   |
|  26 Jun 1954         92  |   29   1970         96   53.70   |
|  10 Jun 1955        126  |   30   1933         96   55.56   |
|  30 Jun 1956        168  |   31   1926         95   57.41   |
|  28 Jun 1957        136  |   32   1954         92   59.26   |
|  24 Jun 1958        201  |   33   1971         89   61.11   |
|  14 Jun 1959         58  |   34   1946         87   62.96   |
|  05 Jun 1960         42  |   35   1953         83   64.81   |
|  26 Oct 1960         25  |   36   1951         82   66.67   |
|  25 Jun 1962        157  |   37   1944         82   68.52   |
|  21 Jun 1963        223  |   38   1950         81   70.37   |
|  07 Jun 1964         70  |   39   1929         77   72.22   |
|  15 Aug 1965        122  |   40   1948         75   74.07   |
|  29 May 1966         70  |   41   1947         75   75.93   |
|  03 Jul 1967        270  |   42   1966         70   77.78   |
|  20 Jun 1968         58  |   43   1964         70   79.63   |
|  04 Jun 1969        206  |   44   1972         65   81.48   |
|  09 Jun 1970         96  |   45   1968         58   83.33   |
|  18 Jun 1971         89  |   46   1959         58   85.19   |
|  09 Jun 1972         65  |   47   1939         55   87.04   |
|  13 Jun 1973        123  |   48   1931         50   88.89   |
|  08 Jun 1974        140  |   49   1934         44   90.74   |
|  17 Jun 1975        167  |   50   1960         42   92.59   |
|  19 May 1976         30  |   51   1977         35   94.44   |
|  10 Jun 1977         35  |   52   1976         30   96.30   |
|  16 Jul 1978        150  |   53   1961         25   98.15   |
|--------------------------|----------------------------------|
```

```
<< Outlier Tests >>
---------------------------------------------------------------
<< Low Outlier Test >>
-----------------------
  Based on 53 events, 10 percent outlier test value K(N) = 2.79

             0 low outlier(s) identified below test value of 23


-----------------------
<< High Outlier Test >>
-----------------------
  Based on 53 events, 10 percent outlier test value K(N) = 2.79

           0 high outlier(s) identified above test value of 448
---------------------------------------------------------------


<< Skew Weighting >>
---------------------------------------------------------------
Based on 53 events, mean-square error of station skew =   0.126
Default or input mean-square error of regional skew =     0.302
---------------------------------------------------------------

<< Frequency Curve >>
CONVICT C-MAMMOTH LAKES CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |       0.05       0.95 |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        387         412 |     0.2    |        518        311 |
|        343         360 |     0.5    |        450        280 |
|        310         322 |     1.0    |        399        256 |
|        276         285 |     2.0    |        350        231 |
|        242         248 |     4.0    |        300        205 |
|        196         198 |    10.0    |        235        169 |
|        159         160 |    20.0    |        185        139 |
|        103         103 |    50.0    |        117         91 |
|         65          64 |    80.0    |         74         55 |
|         50          49 |    90.0    |         58         41 |
|         40          39 |    95.0    |         47         32 |
|         26          24 |    99.0    |         32         19 |
|------------------------|------------|-----------------------|


<< Systematic Statistics >>
CONVICT C-MAMMOTH LAKES CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|        Log Transform:        |                              |
|    FLOW-ANNUAL PEAK, CFS     |       Number of Events       |
|------------------------------|------------------------------|
|  Mean                2.0017  |  Historic Events          0  |
```

```
|  Standard Dev        0.2327  |  High Outliers         0     |
|  Station Skew       -0.4083  |  Low Outliers          0     |
|  Regional Skew       0.1000  |  Zero Events           0     |
|  Weighted Skew      -0.2591  |  Missing Events        0     |
|  Adopted Skew       -0.3000  |  Systematic Events       53  |
|------------------------------|------------------------------|
```

USGS Station 10265700 FFA Results

```
-------------------------------
Bulletin 17B Frequency Analysis
    06 Apr 2007   10:46 AM
-------------------------------


--- Input Data ---

Analysis Name: 10265700
Description:

Data Set Name: ROCK C A LITTLE ROUND VALLEY-BISHOP CA-FLOW-ANNUAL PEAK
DSS File Name: C:\Caltrans\Hydrology\Desert_Hydrology.dss
DSS Pathname: /ROCK C A LITTLE ROUND VALLEY/BISHOP CA/FLOW-ANNUAL
PEAK/01jan1900/IR-CENTURY/USGS/

Report File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10265700\10265700.rpt
XML File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10265700\10265700.xml

Skew Option: Use Regional Skew
Regional Skew: 0.1
Regional Skew MSE: 0.302
Round adopted skew to nearest tenth

Plotting Position Type: Weibull

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use non-standard frequencies
Frequency: 0.2
Frequency: 0.5
Frequency: 1.0
Frequency: 2.0
Frequency: 4.0
Frequency: 10.0
Frequency: 20.0
Frequency: 50.0
Frequency: 80.0
Frequency: 90.0
Frequency: 95.0
Frequency: 99.0

Round ordinate values to 3 significant digits
Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---


--- Final Results ---

<< Plotting Positions >>
ROCK C A LITTLE ROUND VALLEY-BISHOP CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|     Events Analyzed      |          Ordered Events          |
```

```
|                    FLOW  |       Water       FLOW  Weibull  |
| Day Mon Year        CFS  |  Rank  Year        CFS  Plot Pos |
|--------------------------|----------------------------------|
|  14 Jun 1927        205  |    1   1969        312    1.89    |
|  29 May 1928        130  |    2   1952        270    3.77    |
|  30 Jun 1929         75  |    3   1967        266    5.66    |
|  16 Jun 1930         90  |    4   1938        257    7.55    |
|  06 Jun 1931         30  |    5   1963        207    9.43    |
|  27 Jun 1932        168  |    6   1927        205   11.32    |
|  16 Jun 1933        112  |    7   1956        193   13.21    |
|  17 Dec 1933         70  |    8   1978        191   15.09    |
|  13 Jun 1935        107  |    9   1974        182   16.98    |
|  24 Jun 1936        142  |   10   1932        168   18.87    |
|  22 Jun 1937        151  |   11   1973        160   20.75    |
|  27 Jun 1938        257  |   12   1958        159   22.64    |
|  31 May 1939         78  |   13   1955        153   24.53    |
|  15 Jun 1940        118  |   14   1937        151   26.42    |
|  16 Jun 1941        145  |   15   1957        147   28.30    |
|  06 Jul 1942        120  |   16   1941        145   30.19    |
|  28 May 1943        116  |   17   1962        144   32.08    |
|  03 Jul 1944         79  |   18   1945        143   33.96    |
|  03 Jul 1945        143  |   19   1936        142   35.85    |
|  26 Jul 1946        119  |   20   1949        141   37.74    |
|  25 May 1947         89  |   21   1975        138   39.62    |
|  30 Jun 1948         77  |   22   1953        135   41.51    |
|  12 Jun 1949        141  |   23   1928        130   43.40    |
|  03 Jun 1950        121  |   24   1950        121   45.28    |
|  22 Jun 1951        117  |   25   1942        120   47.17    |
|  26 Jul 1952        270  |   26   1946        119   49.06    |
|  18 Jul 1953        135  |   27   1940        118   50.94    |
|  21 May 1954         98  |   28   1951        117   52.83    |
|  11 Jun 1955        153  |   29   1943        116   54.72    |
|  30 Jun 1956        193  |   30   1933        112   56.60    |
|  05 Jun 1957        147  |   31   1965        110   58.49    |
|  24 Jun 1958        159  |   32   1935        107   60.38    |
|  13 Jun 1959         54  |   33   1970        100   62.26    |
|  05 Jun 1960         55  |   34   1954         98   64.15    |
|  20 Jun 1961         58  |   35   1930         90   66.04    |
|  24 Jun 1962        144  |   36   1947         89   67.92    |
|  20 Jun 1963        207  |   37   1971         88   69.81    |
|  27 Jun 1964         56  |   38   1944         79   71.70    |
|  08 Jul 1965        110  |   39   1939         78   73.58    |
|  20 Jun 1966         59  |   40   1948         77   75.47    |
|  03 Jul 1967        266  |   41   1929         75   77.36    |
|  05 Jun 1968         54  |   42   1934         70   79.25    |
|  30 May 1969        312  |   43   1972         66   81.13    |
|  28 Jun 1970        100  |   44   1966         59   83.02    |
|  18 Jun 1971         88  |   45   1961         58   84.91    |
|  08 Jun 1972         66  |   46   1964         56   86.79    |
|  31 May 1973        160  |   47   1960         55   88.68    |
|  08 Jun 1974        182  |   48   1977         54   90.57    |
|  07 Jun 1975        138  |   49   1968         54   92.45    |
|  28 Jul 1976         46  |   50   1959         54   94.34    |
|  28 Jun 1977         54  |   51   1976         46   96.23    |
|  09 Jun 1978        191  |   52   1931         30   98.11    |
|--------------------------|----------------------------------|
```

```
<< Outlier Tests >>
---------------------------------------------------------------
<< Low Outlier Test >>
-----------------------
 Based on 52 events, 10 percent outlier test value K(N) = 2.783

             0 low outlier(s) identified below test value of 27


-----------------------
<< High Outlier Test >>
-----------------------
 Based on 52 events, 10 percent outlier test value K(N) = 2.783

           0 high outlier(s) identified above test value of 458
---------------------------------------------------------------


<< Skew Weighting >>
---------------------------------------------------------------
Based on 52 events, mean-square error of station skew =   0.116
Default or input mean-square error of regional skew =     0.302
---------------------------------------------------------------

<< Frequency Curve >>
ROCK C A LITTLE ROUND VALLEY-BISHOP CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |       0.05       0.95 |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        426         456 |     0.2    |        568        343 |
|        375         395 |     0.5    |        490        307 |
|        337         352 |     1.0    |        433        279 |
|        300         310 |     2.0    |        377        251 |
|        262         268 |     4.0    |        323        223 |
|        212         214 |    10.0    |        252        184 |
|        172         173 |    20.0    |        200        152 |
|        114         114 |    50.0    |        128        101 |
|         73          73 |    80.0    |         83         63 |
|         58          57 |    90.0    |         67         48 |
|         47          46 |    95.0    |         56         38 |
|         32          30 |    99.0    |         39         24 |
|------------------------|------------|-----------------------|


<< Systematic Statistics >>
ROCK C A LITTLE ROUND VALLEY-BISHOP CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|        Log Transform:        |                              |
|    FLOW-ANNUAL PEAK, CFS     |       Number of Events       |
|------------------------------|------------------------------|
|  Mean                 2.0484 |  Historic Events          0  |
|  Standard Dev         0.2202 |  High Outliers         0     |
```

```
|  Station Skew       -0.2556  |  Low Outliers          0     |
|  Regional Skew       0.1000  |  Zero Events           0     |
|  Weighted Skew      -0.1568  |  Missing Events        0     |
|  Adopted Skew       -0.2000  |  Systematic Events       52  |
|------------------------------|------------------------------|
```

USGS Station 10267000 FFA Results

```
-------------------------------
Bulletin 17B Frequency Analysis
    06 Apr 2007   11:06 AM
-------------------------------


--- Input Data ---

Analysis Name: 10267000
Description:

Data Set Name: PINE C A DIVISION BOX-BISHOP CA-FLOW-ANNUAL PEAK
DSS File Name: C:\Caltrans\Hydrology\Desert_Hydrology.dss
DSS Pathname: /PINE C A DIVISION BOX/BISHOP CA/FLOW-ANNUAL
PEAK/01jan1900/IR-CENTURY/USGS/

Report File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10267000\10267000.rpt
XML File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10267000\10267000.xml

Skew Option: Use Regional Skew
Regional Skew: 0.1
Regional Skew MSE: 0.302
Round adopted skew to nearest tenth

Plotting Position Type: Weibull

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use non-standard frequencies
Frequency: 0.2
Frequency: 0.5
Frequency: 1.0
Frequency: 2.0
Frequency: 4.0
Frequency: 10.0
Frequency: 20.0
Frequency: 50.0
Frequency: 80.0
Frequency: 90.0
Frequency: 95.0
Frequency: 99.0

Round ordinate values to 3 significant digits
Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---


--- Preliminary Results ---


<< Skew Weighting >>
---------------------------------------------------------------
Based on 58 events, mean-square error of station skew =   0.154
```

```
Default or input mean-square error of regional skew =     0.302
---------------------------------------------------------------

<< Frequency Curve >>
PINE C A DIVISION BOX-BISHOP CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |       0.05       0.95 |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        607         629 |     0.2    |        750        515 |
|        561         577 |     0.5    |        686        480 |
|        524         537 |     1.0    |        633        452 |
|        484         493 |     2.0    |        578        421 |
|        441         447 |     4.0    |        519        387 |
|        377         380 |    10.0    |        435        335 |
|        321         322 |    20.0    |        363        289 |
|        227         227 |    50.0    |        251        206 |
|        153         151 |    80.0    |        169        135 |
|        121         119 |    90.0    |        137        104 |
|         99          97 |    95.0    |        114         83 |
|         66          62 |    99.0    |         79         52 |
|------------------------|------------|-----------------------|


<< Systematic Statistics >>
PINE C A DIVISION BOX-BISHOP CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|        Log Transform:        |                              |
|    FLOW-ANNUAL PEAK, CFS     |       Number of Events       |
|------------------------------|------------------------------|
|  Mean                 2.3401 |  Historic Events          0  |
|  Standard Dev         0.1939 |  High Outliers         0     |
|  Station Skew        -0.8447 |  Low Outliers          0     |
|  Regional Skew        0.1000 |  Zero Events           0     |
|  Weighted Skew       -0.5256 |  Missing Events        0     |
|  Adopted Skew        -0.5000 |  Systematic Events       58  |
|------------------------------|------------------------------|

--- End of Preliminary Results ---



--- Final Results ---

<< Plotting Positions >>
PINE C A DIVISION BOX-BISHOP CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|     Events Analyzed      |          Ordered Events          |
|                    FLOW  |       Water      FLOW  Weibull  |
| Day Mon Year        CFS  |  Rank  Year        CFS  Plot Pos |
|--------------------------|----------------------------------|
|  26 Jun 1922        310  |    1   1967        509    1.69   |
|  02 Jul 1923        201  |    2   1969        472    3.39   |
|  09 May 1924         90  |    3   1957        356    5.08   |
|  28 Jun 1925        153  |    4   1936        350    6.78   |
|  19 May 1926        167  |    5   1941        345    8.47   |
```

```
|  16 Jun 1927        295 |    6   1963        343   10.17    |
|  28 May 1928        186 |    7   1956        339   11.86    |
|  29 Jun 1929        127 |    8   1945        330   13.56    |
|  12 Jun 1930        125 |    9   1938        329   15.25    |
|  18 May 1931         61 |   10   1932        325   16.95    |
|  25 Jun 1932        325 |   11   1958        317   18.64    |
|  14 Jun 1933        195 |   12   1974        314   20.34    |
|  13 May 1934         71 |   13   1922        310   22.03    |
|  05 Jun 1935        228 |   14   1955        303   23.73    |
|  21 Jul 1936        350 |   15   1962        298   25.42    |
|  21 Jun 1937        274 |   16   1942        297   27.12    |
|  25 Jun 1938        329 |   17   1973        296   28.81    |
|  29 May 1939        169 |   18   1927        295   30.51    |
|  17 Jun 1940        268 |   19   1952        288   32.20    |
|  08 Jul 1941        345 |   20   1949        283   33.90    |
|  04 Jul 1942        297 |   21   1943        281   35.59    |
|  27 May 1943        281 |   22   1937        274   37.29    |
|  01 Jul 1944        204 |   23   1972        269   38.98    |
|  20 Jun 1945        330 |   24   1953        269   40.68    |
|  24 Jul 1946        265 |   25   1940        268   42.37    |
|  22 May 1947        238 |   26   1946        265   44.07    |
|  22 Jun 1948        187 |   27   1978        264   45.76    |
|  10 Jun 1949        283 |   28   1951        255   47.46    |
|  31 May 1950        217 |   29   1947        238   49.15    |
|  18 Jun 1951        255 |   30   1975        234   50.85    |
|  06 Jun 1952        288 |   31   1979        232   52.54    |
|  17 Jul 1953        269 |   32   1935        228   54.24    |
|  20 May 1954        222 |   33   1965        225   55.93    |
|  10 Jun 1955        303 |   34   1954        222   57.63    |
|  30 Jun 1956        339 |   35   1950        217   59.32    |
|  04 Jun 1957        356 |   36   1970        215   61.02    |
|  23 Jun 1958        317 |   37   1971        207   62.71    |
|  06 Jun 1959        144 |   38   1944        204   64.41    |
|  04 Jun 1960        147 |   39   1923        201   66.10    |
|  08 Jun 1961        117 |   40   1933        195   67.80    |
|  23 Jun 1962        298 |   41   1948        187   69.49    |
|  20 Jun 1963        343 |   42   1928        186   71.19    |
|  07 Jun 1964        140 |   43   1939        169   72.88    |
|  07 Jul 1965        225 |   44   1926        167   74.58    |
|  27 May 1966        156 |   45   1966        156   76.27    |
|  02 Jul 1967        509 |   46   1925        153   77.97    |
|  03 Jun 1968        147 |   47   1968        147   79.66    |
|  03 Jun 1969        472 |   48   1960        147   81.36    |
|  27 Jun 1970        215 |   49   1959        144   83.05    |
|  17 Jun 1971        207 |   50   1964        140   84.75    |
|  05 Sep 1972        269 |   51   1929        127   86.44    |
|  27 Jun 1973        296 |   52   1930        125   88.14    |
|  06 Jun 1974        314 |   53   1961        117   89.83    |
|  07 Jun 1975        234 |   54   1977        101   91.53    |
|  14 May 1976         94 |   55   1976         94   93.22    |
|  09 Jun 1977        101 |   56   1924         90   94.92    |
|  09 Jun 1978        264 |   57   1934         71   96.61    |
|  27 May 1979        232 |   58   1931         61*  98.31    |
|-------------------------|----------------------------------|
                                                  * Outlier
```

```
<< Outlier Tests >>
---------------------------------------------------------------
<< Low Outlier Test >>
-----------------------
 Based on 58 events, 10 percent outlier test value K(N) = 2.824

             1 low outlier(s) identified below test value of 62

Statistics and frequency curve adjusted for 1 low outliers.

-----------------------
<< High Outlier Test >>
-----------------------
 Based on 57 events, 10 percent outlier test value K(N) = 2.818

           0 high outlier(s) identified above test value of 723
---------------------------------------------------------------


<< Skew Weighting >>
---------------------------------------------------------------
Based on 58 events, mean-square error of station skew =   0.139
Default or input mean-square error of regional skew =     0.302
---------------------------------------------------------------

<< Frequency Curve >>
PINE C A DIVISION BOX-BISHOP CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |       0.05       0.95 |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        606         630 |     0.2    |        746        517 |
|        558         575 |     0.5    |        678        480 |
|        519         533 |     1.0    |        624        451 |
|        478         488 |     2.0    |        567        419 |
|        435         441 |     4.0    |        509        384 |
|        372         375 |    10.0    |        425        333 |
|        317         319 |    20.0    |        357        287 |
|        228         228 |    50.0    |        250        208 |
|        157         156 |    80.0    |        174        140 |
|        128         126 |    90.0    |        143        111 |
|        106         104 |    95.0    |        121         90 |
|         74          70 |    99.0    |         88         59 |
|------------------------|------------|-----------------------|


<< Synthetic Statistics >>
PINE C A DIVISION BOX-BISHOP CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|        Log Transform:        |                              |
|    FLOW-ANNUAL PEAK, CFS     |       Number of Events       |
|------------------------------|------------------------------|
|  Mean                2.3459  |  Historic Events          0  |
|  Standard Dev        0.1821  |  High Outliers         0     |
```

```
|  Station Skew       -0.6874  |  Low Outliers          1     |
|  Regional Skew       0.1000  |  Zero Events           0     |
|  Weighted Skew      -0.4389  |  Missing Events        0     |
|  Adopted Skew       -0.4000  |  Systematic Events       58  |
|------------------------------|------------------------------|
```

USGS Station 10276000 FFA Results

```
-------------------------------
Bulletin 17B Frequency Analysis
    06 Apr 2007   11:15 AM
-------------------------------


--- Input Data ---

Analysis Name: 10276000
Description:

Data Set Name: BIG PINE C-BIG PINE CA-FLOW-ANNUAL PEAK
DSS File Name: C:\Caltrans\Hydrology\Desert_Hydrology.dss
DSS Pathname: /BIG PINE C/BIG PINE CA/FLOW-ANNUAL PEAK/01jan1900/IR-
CENTURY/USGS/

Report File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10276000\10276000.rpt
XML File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10276000\10276000.xml

Skew Option: Use Regional Skew
Regional Skew: 0.1
Regional Skew MSE: 0.302
Round adopted skew to nearest tenth

Plotting Position Type: Weibull

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use non-standard frequencies
Frequency: 0.2
Frequency: 0.5
Frequency: 1.0
Frequency: 2.0
Frequency: 4.0
Frequency: 10.0
Frequency: 20.0
Frequency: 50.0
Frequency: 80.0
Frequency: 90.0
Frequency: 95.0
Frequency: 99.0

Round ordinate values to 3 significant digits
Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---


--- Final Results ---

<< Plotting Positions >>
BIG PINE C-BIG PINE CA-FLOW-ANNUAL PEAK
----------------------------------------------------------------
|     Events Analyzed      |          Ordered Events           |
```

```
|                    FLOW  |       Water       FLOW  Weibull  |
| Day Mon Year        CFS  |  Rank  Year        CFS  Plot Pos |
|--------------------------|----------------------------------|
|  15 Jul 1908        166  |    1   1932        458    1.59   |
|  17 Jun 1909        258  |    2   1969        397    3.17   |
|  19 Jul 1910        252  |    3   1978        353    4.76   |
|  22 Jun 1920        127  |    4   1967        339    6.35   |
|  21 Jul 1921        152  |    5   1938        298    7.94   |
|  06 Jul 1922        246  |    6   1937        291    9.52   |
|  12 Aug 1923        125  |    7   1955        287   11.11   |
|  04 Jul 1924         98  |    8   1941        284   12.70   |
|  19 Jul 1925        190  |    9   1953        283   14.29   |
|  20 May 1926        113  |   10   1965        266   15.87   |
|  26 Jun 1927        257  |   11   1935        266   17.46   |
|  03 Jun 1928        153  |   12   1942        264   19.05   |
|  01 Jul 1929        184  |   13   1972        262   20.63   |
|  17 Jul 1930        125  |   14   1909        258   22.22   |
|  09 Jul 1931        120  |   15   1927        257   23.81   |
|  03 Jul 1932        458  |   16   1910        252   25.40   |
|  14 Jul 1933        191  |   17   1956        251   26.98   |
|  01 Aug 1934        113  |   18   1945        247   28.57   |
|  17 Jul 1935        266  |   19   1922        246   30.16   |
|  22 Jul 1936        188  |   20   1952        245   31.75   |
|  06 Jul 1937        291  |   21   1958        214   33.33   |
|  25 Jul 1938        298  |   22   1949        212   34.92   |
|  30 Jul 1939        209  |   23   1939        209   36.51   |
|  15 Jun 1940        184  |   24   1974        206   38.10   |
|  24 Jul 1941        284  |   25   1963        203   39.68   |
|  05 Jul 1942        264  |   26   1957        200   41.27   |
|  06 Jul 1943        129  |   27   1973        192   42.86   |
|  30 Jun 1944        109  |   28   1970        192   44.44   |
|  02 Aug 1945        247  |   29   1933        191   46.03   |
|  04 Jul 1946        185  |   30   1925        190   47.62   |
|  20 Jun 1947        122  |   31   1936        188   49.21   |
|  26 Jun 1948        111  |   32   1968        185   50.79   |
|  12 Jun 1949        212  |   33   1946        185   52.38   |
|  03 Jun 1950        151  |   34   1940        184   53.97   |
|  17 Jun 1951        155  |   35   1929        184   55.56   |
|  31 Jul 1952        245  |   36   1975        183   57.14   |
|  17 Jul 1953        283  |   37   1962        183   58.73   |
|  24 Jun 1954        171  |   38   1976        173   60.32   |
|  05 Aug 1955        287  |   39   1954        171   61.90   |
|  22 Jul 1956        251  |   40   1908        166   63.49   |
|  27 Jun 1957        200  |   41   1951        155   65.08   |
|  24 Jun 1958        214  |   42   1928        153   66.67   |
|  16 Jun 1959        102  |   43   1921        152   68.25   |
|  26 Jul 1960         91  |   44   1950        151   69.84   |
|  22 Aug 1961        108  |   45   1971        147   71.43   |
|  08 Jul 1962        183  |   46   1943        129   73.02   |
|  21 Jun 1963        203  |   47   1966        127   74.60   |
|  07 Aug 1964         76  |   48   1920        127   76.19   |
|  12 Aug 1965        266  |   49   1930        125   77.78   |
|  28 Jun 1966        127  |   50   1923        125   79.37   |
|  05 Jul 1967        339  |   51   1947        122   80.95   |
|  30 Jul 1968        185  |   52   1931        120   82.54   |
|  22 Jul 1969        397  |   53   1934        113   84.13   |
|  09 Jul 1970        192  |   54   1926        113   85.71   |
```

```
|  18 Jul 1971        147  |   55   1948         111   87.30   |
|  05 Sep 1972        262  |   56   1944         109   88.89   |
|  09 Jun 1973        192  |   57   1961         108   90.48   |
|  14 Jun 1974        206  |   58   1959         102   92.06   |
|  16 Jun 1975        183  |   59   1924          98   93.65   |
|  11 Sep 1976        173  |   60   1960          91   95.24   |
|  25 Jun 1977         83  |   61   1977          83   96.83   |
|  05 Sep 1978        353  |   62   1964          76   98.41   |
|--------------------------|-----------------------------------|



<< Outlier Tests >>
----------------------------------------------------------------
<< Low Outlier Test >>
-----------------------
 Based on 62 events, 10 percent outlier test value K(N) = 2.849

              0 low outlier(s) identified below test value of 59


-----------------------
<< High Outlier Test >>
-----------------------
 Based on 62 events, 10 percent outlier test value K(N) = 2.849

            0 high outlier(s) identified above test value of 571
----------------------------------------------------------------


<< Skew Weighting >>
----------------------------------------------------------------
Based on 62 events, mean-square error of station skew =   0.089
Default or input mean-square error of regional skew =     0.302
----------------------------------------------------------------

<< Frequency Curve >>
BIG PINE C-BIG PINE CA-FLOW-ANNUAL PEAK
----------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |       0.05       0.95 |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        578         610 |     0.2    |         720         488 |
|        512         534 |     0.5    |         626         439 |
|        463         479 |     1.0    |         558         401 |
|        416         426 |     2.0    |         492         364 |
|        368         375 |     4.0    |         429         327 |
|        305         308 |    10.0    |         346         275 |
|        256         257 |    20.0    |         285         234 |
|        183         183 |    50.0    |         199         168 |
|        131         130 |    80.0    |         143         118 |
|        110         109 |    90.0    |         122          97 |
|         95          93 |    95.0    |         107          82 |
|         72          70 |    99.0    |          83          60 |
|------------------------|------------|-----------------------|
```

```
<< Systematic Statistics >>
BIG PINE C-BIG PINE CA-FLOW-ANNUAL PEAK
--------------------------------------------------------------
|        Log Transform:         |                              |
|    FLOW-ANNUAL PEAK, CFS      |       Number of Events       |
|-------------------------------|------------------------------|
|  Mean                 2.2623  |  Historic Events          0  |
|  Standard Dev         0.1735  |  High Outliers         0     |
|  Station Skew        -0.0929  |  Low Outliers          0     |
|  Regional Skew        0.1000  |  Zero Events           0     |
|  Weighted Skew       -0.0488  |  Missing Events        0     |
|  Adopted Skew        -0.0000  |  Systematic Events       62  |
|-------------------------------|------------------------------|
```

USGS Station 10281800 FFA Results

```
-------------------------------
Bulletin 17B Frequency Analysis
    06 Apr 2007   11:19 AM
-------------------------------


--- Input Data ---

Analysis Name: 10281800
Description:

Data Set Name: INDEPENDENCE C BL PINYON C-INDEPENDENCE CA-FLOW-ANNUAL
PEAK
DSS File Name: C:\Caltrans\Hydrology\Desert_Hydrology.dss
DSS Pathname: /INDEPENDENCE C BL PINYON C/INDEPENDENCE CA/FLOW-ANNUAL
PEAK/01jan1900/IR-CENTURY/USGS/

Report File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10281800\10281800.rpt
XML File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10281800\10281800.xml

Skew Option: Use Regional Skew
Regional Skew: 0.1
Regional Skew MSE: 0.302
Round adopted skew to nearest tenth

Plotting Position Type: Weibull

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use non-standard frequencies
Frequency: 0.2
Frequency: 0.5
Frequency: 1.0
Frequency: 2.0
Frequency: 4.0
Frequency: 10.0
Frequency: 20.0
Frequency: 50.0
Frequency: 80.0
Frequency: 90.0
Frequency: 95.0
Frequency: 99.0

Round ordinate values to 3 significant digits
Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---


--- Final Results ---

<< Plotting Positions >>
INDEPENDENCE C BL PINYON C-INDEPENDENCE CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
```

```
|     Events Analyzed      |          Ordered Events          |
|                    FLOW  |       Water       FLOW  Weibull  |
| Day Mon Year        CFS  |  Rank  Year        CFS  Plot Pos |
|--------------------------|----------------------------------|
|  03 Jul 1923         36  |     1  1969        169     1.75   |
|  18 May 1924         14  |     2  1963        138     3.51   |
|  28 Jun 1925         52  |     3  1967        119     5.26   |
|  21 May 1926         43  |     4  1941        106     7.02   |
|  19 Jun 1927        100  |     5  1952        102     8.77   |
|  05 Jun 1928         63  |     6  1927        100    10.53   |
|  30 Jun 1929         30  |     7  1956         99    12.28   |
|  15 Jun 1930         65  |     8  1958         97    14.04   |
|  05 Jun 1931         14  |     9  1938         95    15.79   |
|  25 Jun 1932         90  |    10  1957         94    17.54   |
|  16 Jun 1933         56  |    11  1965         91    19.30   |
|  15 May 1934         11  |    12  1932         90    21.05   |
|  13 Jun 1935         57  |    13  1943         86    22.81   |
|  23 Jun 1936         74  |    14  1937         80    24.56   |
|  22 Jun 1937         80  |    15  1940         78    26.32   |
|  03 Jun 1938         95  |    16  1945         77    28.07   |
|  31 May 1939         55  |    17  1962         76    29.82   |
|  15 Jun 1940         78  |    18  1936         74    31.58   |
|  16 Jun 1941        106  |    19  1942         70    33.33   |
|  18 Jun 1942         70  |    20  1954         65    35.09   |
|  28 May 1943         86  |    21  1930         65    36.84   |
|  08 Jun 1944         62  |    22  1928         63    38.60   |
|  21 Jun 1945         77  |    23  1944         62    40.35   |
|  04 Jun 1946         41  |    24  1973         59    42.11   |
|  23 May 1947         50  |    25  1951         58    43.86   |
|  27 Jun 1948         38  |    26  1955         57    45.61   |
|  15 Jun 1949         54  |    27  1935         57    47.37   |
|  02 Jun 1950         45  |    28  1933         56    49.12   |
|  17 Jun 1951         58  |    29  1974         55    50.88   |
|  29 May 1952        102  |    30  1939         55    52.63   |
|  09 Jul 1953         42  |    31  1949         54    54.39   |
|  22 May 1954         65  |    32  1925         52    56.14   |
|  10 Jun 1955         57  |    33  1947         50    57.89   |
|  30 Jun 1956         99  |    34  1978         49    59.65   |
|  08 Jun 1957         94  |    35  1975         47    61.40   |
|  24 Jun 1958         97  |    36  1950         45    63.16   |
|  24 Jun 1959         21  |    37  1926         43    64.91   |
|  18 Jun 1960         19  |    38  1970         42    66.67   |
|  19 Jun 1961         17  |    39  1953         42    68.42   |
|  23 Jun 1962         76  |    40  1971         41    70.18   |
|  21 Jun 1963        138  |    41  1946         41    71.93   |
|  07 Jun 1964         31  |    42  1948         38    73.68   |
|  12 Jun 1965         91  |    43  1923         36    75.44   |
|  21 Jun 1966         23  |    44  1968         31    77.19   |
|  04 Jul 1967        119  |    45  1964         31    78.95   |
|  05 Jun 1968         31  |    46  1929         30    80.70   |
|  01 Jun 1969        169  |    47  1976         28    82.46   |
|  09 Jul 1970         42  |    48  1977         24    84.21   |
|  18 Jun 1971         41  |    49  1966         23    85.96   |
|  08 Jun 1972         18  |    50  1959         21    87.72   |
|  09 Jun 1973         59  |    51  1960         19    89.47   |
|  29 May 1974         55  |    52  1972         18    91.23   |
|  07 Jun 1975         47  |    53  1961         17    92.98   |
```

```
|  11 Sep 1976         28  |   54   1931         14   94.74   |
|  09 Jun 1977         24  |   55   1924         14   96.49   |
|  27 Jul 1978         49  |   56   1934         11   98.25   |
|--------------------------|----------------------------------|



<< Outlier Tests >>
---------------------------------------------------------------
<< Low Outlier Test >>
-----------------------
 Based on 56 events, 10 percent outlier test value K(N) = 2.811

              0 low outlier(s) identified below test value of 9


-----------------------
<< High Outlier Test >>
-----------------------
 Based on 56 events, 10 percent outlier test value K(N) = 2.811

           0 high outlier(s) identified above test value of 287
---------------------------------------------------------------


<< Skew Weighting >>
---------------------------------------------------------------
Based on 56 events, mean-square error of station skew =   0.133
Default or input mean-square error of regional skew =     0.302
---------------------------------------------------------------

<< Frequency Curve >>
INDEPENDENCE C BL PINYON C-INDEPENDENCE CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |       0.05       0.95 |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        223         236 |     0.2    |        304        176 |
|        197         207 |     0.5    |        264        158 |
|        177         184 |     1.0    |        234        143 |
|        157         162 |     2.0    |        203        129 |
|        137         140 |     4.0    |        173        113 |
|        108         110 |    10.0    |        133         92 |
|         86          87 |    20.0    |        102         74 |
|         53          53 |    50.0    |         61         46 |
|         31          30 |    80.0    |         36         26 |
|         22          22 |    90.0    |         27         18 |
|         17          17 |    95.0    |         21         13 |
|         10           9 |    99.0    |         13          7 |
|------------------------|------------|-----------------------|


<< Systematic Statistics >>
INDEPENDENCE C BL PINYON C-INDEPENDENCE CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
```

```
|        Log Transform:        |                              |
|    FLOW-ANNUAL PEAK, CFS     |       Number of Events       |
|------------------------------|------------------------------|
|  Mean                1.7054  |  Historic Events          0  |
|  Standard Dev        0.2678  |  High Outliers         0     |
|  Station Skew       -0.5673  |  Low Outliers          0     |
|  Regional Skew       0.1000  |  Zero Events           0     |
|  Weighted Skew      -0.3637  |  Missing Events        0     |
|  Adopted Skew       -0.4000  |  Systematic Events       56  |
|------------------------------|------------------------------|
```

USGS Station 10286000 FFA Results

```
-------------------------------
Bulletin 17B Frequency Analysis
    06 Apr 2007   11:22 AM
-------------------------------


--- Input Data ---

Analysis Name: 10286000
Description:

Data Set Name: COTTONWOOD C-OLANCHA CA-FLOW-ANNUAL PEAK
DSS File Name: C:\Caltrans\Hydrology\Desert_Hydrology.dss
DSS Pathname: /COTTONWOOD C/OLANCHA CA/FLOW-ANNUAL PEAK/01jan1900/IR-
CENTURY/USGS/

Report File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10286000\10286000.rpt
XML File Name:
C:\Caltrans\Hydrology\Bulletin17bResults\10286000\10286000.xml

Skew Option: Use Regional Skew
Regional Skew: 0.1
Regional Skew MSE: 0.302
Round adopted skew to nearest tenth

Plotting Position Type: Weibull

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use non-standard frequencies
Frequency: 0.2
Frequency: 0.5
Frequency: 1.0
Frequency: 2.0
Frequency: 4.0
Frequency: 10.0
Frequency: 20.0
Frequency: 50.0
Frequency: 80.0
Frequency: 90.0
Frequency: 95.0
Frequency: 99.0

Round ordinate values to 3 significant digits
Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---


--- Preliminary Results ---


<< Skew Weighting >>
----------------------------------------------------------------
Based on 68 events, mean-square error of station skew =   0.246
```

```
Default or input mean-square error of regional skew =     0.302
---------------------------------------------------------------

<< Frequency Curve >>
COTTONWOOD C-OLANCHA CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |       0.05       0.95 |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        746         782 |     0.2    |      1,100        548 |
|        656         683 |     0.5    |        953        488 |
|        584         605 |     1.0    |        835        440 |
|        509         523 |     2.0    |        714        388 |
|        429         439 |     4.0    |        589        332 |
|        319         324 |    10.0    |        423        253 |
|        233         234 |    20.0    |        298        188 |
|        113         113 |    50.0    |        138         93 |
|         47          46 |    80.0    |         58         37 |
|         28          27 |    90.0    |         35         21 |
|         17          16 |    95.0    |         23         12 |
|          7           6 |    99.0    |         10          4 |
|------------------------|------------|-----------------------|


<< Systematic Statistics >>
COTTONWOOD C-OLANCHA CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|        Log Transform:        |                              |
|    FLOW-ANNUAL PEAK, CFS     |       Number of Events       |
|------------------------------|------------------------------|
|  Mean                2.0051  |  Historic Events         0   |
|  Standard Dev        0.4217  |  High Outliers        0      |
|  Station Skew       -1.3422  |  Low Outliers         0      |
|  Regional Skew       0.1000  |  Zero Events          0      |
|  Weighted Skew      -0.6950  |  Missing Events       0      |
|  Adopted Skew       -0.7000  |  Systematic Events      68   |
|------------------------------|------------------------------|

--- End of Preliminary Results ---



--- Final Results ---

<< Plotting Positions >>
COTTONWOOD C-OLANCHA CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|     Events Analyzed      |          Ordered Events          |
|                    FLOW  |       Water       FLOW  Weibull  |
| Day Mon Year        CFS  |  Rank  Year        CFS  Plot Pos |
|--------------------------|----------------------------------|
|  13 Jun 1906        434  |    1   1969        520    1.45   |
|  04 Jun 1907        157  |    2   1906        434    2.90   |
|  02 Jun 1908        108  |    3   1909        366    4.35   |
|  03 Jun 1909        366  |    4   1941        321    5.80   |
|  15 Sep 1910        121  |    5   1922        303    7.25   |
```

```
|  01 Jun 1914        275  |    6  1937         280    8.70   |
|  01 Jun 1915        235  |    7  1967         276   10.14   |
|  06 May 1916        221  |    8  1914         275   11.59   |
|  21 Jun 1917        136  |    9  1932         259   13.04   |
|  21 Jun 1918        237  |   10  1958         256   14.49   |
|  28 May 1919        135  |   11  1952         256   15.94   |
|  20 May 1920        156  |   12  1918         237   17.39   |
|  26 May 1921        110  |   13  1915         235   18.84   |
|  06 May 1922        303  |   14  1916         221   20.29   |
|  12 May 1923        141  |   15  1938         210   21.74   |
|  18 Apr 1924        100  |   16  1973         187   23.19   |
|  06 May 1925         52  |   17  1927         186   24.64   |
|  04 May 1926         98  |   18  1945         180   26.09   |
|  16 May 1927        186  |   19  1943         180   27.54   |
|  10 May 1928         51  |   20  1942         169   28.99   |
|  03 May 1929         47  |   21  1946         162   30.43   |
|  24 May 1930         84  |   22  1962         157   31.88   |
|  09 Apr 1931         21  |   23  1907         157   33.33   |
|  20 May 1932        259  |   24  1920         156   34.78   |
|  06 Jun 1933         70  |   25  1944         143   36.23   |
|  20 Apr 1934         44  |   26  1963         142   37.68   |
|  21 May 1935         83  |   27  1923         141   39.13   |
|  04 May 1936        138  |   28  1936         138   40.58   |
|  15 May 1937        280  |   29  1917         136   42.03   |
|  26 May 1938        210  |   30  1919         135   43.48   |
|  21 Apr 1939        102  |   31  1957         130   44.93   |
|  09 May 1940        122  |   32  1947         129   46.38   |
|  05 Jun 1941        321  |   33  1965         125   47.83   |
|  24 May 1942        169  |   34  1940         122   49.28   |
|  06 May 1943        180  |   35  1974         121   50.72   |
|  23 May 1944        143  |   36  1910         121   52.17   |
|  16 May 1945        180  |   37  1956         119   53.62   |
|  04 May 1946        162  |   38  1949         114   55.07   |
|  05 May 1947        129  |   39  1954         113   56.52   |
|  27 Apr 1948         84  |   40  1921         110   57.97   |
|  24 Apr 1949        114  |   41  1908         108   59.42   |
|  26 Apr 1950         81  |   42  1939         102   60.87   |
|  19 May 1951         26  |   43  1924         100   62.32   |
|  30 May 1952        256  |   44  1926          98   63.77   |
|  19 May 1953         52  |   45  1975          89   65.22   |
|  08 May 1954        113  |   46  1948          84   66.67   |
|  18 May 1955         21  |   47  1930          84   68.12   |
|  23 May 1956        119  |   48  1935          83   69.57   |
|  05 Jun 1957        130  |   49  1976          82   71.01   |
|  22 May 1958        256  |   50  1950          81   72.46   |
|  13 Apr 1959         15  |   51  1933          70   73.91   |
|  05 Apr 1960          8  |   52  1970          67   75.36   |
|  13 May 1961        2.8  |   53  1968          57   76.81   |
|  07 May 1962        157  |   54  1953          52   78.26   |
|  20 Jun 1963        142  |   55  1925          52   79.71   |
|  10 May 1964         27  |   56  1928          51   81.16   |
|  19 May 1965        125  |   57  1966          49   82.61   |
|  26 Dec 1965         49  |   58  1971          47   84.06   |
|  26 May 1967        276  |   59  1929          47   85.51   |
|  04 May 1968         57  |   60  1934          44   86.96   |
|  03 Jun 1969        520  |   61  1964          27   88.41   |
|  16 May 1970         67  |   62  1951          26   89.86   |
```

```
|  13 May 1971         47  |   63   1955         21   91.30   |
|  14 Mar 1972          8  |   64   1931         21   92.75   |
|  31 May 1973        187  |   65   1959         15   94.20   |
|  14 May 1974        121  |   66   1972          8   95.65   |
|  19 May 1975         89  |   67   1960          8   97.10   |
|  10 Sep 1976         82  |   68   1961        2.8*  98.55   |
|--------------------------|---------------------------------|
                                                 * Outlier



<< Outlier Tests >>
---------------------------------------------------------------
<< Low Outlier Test >>
-----------------------
 Based on 68 events, 10 percent outlier test value K(N) = 2.883

              1 low outlier(s) identified below test value of 6

Statistics and frequency curve adjusted for 1 low outliers.

-----------------------
<< High Outlier Test >>
-----------------------
 Based on 67 events, 10 percent outlier test value K(N) = 2.877

         0 high outlier(s) identified above test value of 1,309
---------------------------------------------------------------


<< Skew Weighting >>
---------------------------------------------------------------
Based on 68 events, mean-square error of station skew =   0.164
Default or input mean-square error of regional skew =     0.302
---------------------------------------------------------------

<< Frequency Curve >>
COTTONWOOD C-OLANCHA CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |      0.05      0.95   |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        720         758 |     0.2    |      1,040        537 |
|        628         656 |     0.5    |        894        475 |
|        557         577 |     1.0    |        779        426 |
|        483         497 |     2.0    |        663        375 |
|        407         416 |     4.0    |        546        321 |
|        304         308 |    10.0    |        394        245 |
|        224         226 |    20.0    |        281        184 |
|        114         114 |    50.0    |        137         96 |
|         51          51 |    80.0    |         62         41 |
|         32          31 |    90.0    |         40         24 |
|         21          20 |    95.0    |         27         15 |
|          9           8 |    99.0    |         13          6 |
|------------------------|------------|-----------------------|
```

```
<< Synthetic Statistics >>
COTTONWOOD C-OLANCHA CA-FLOW-ANNUAL PEAK
--------------------------------------------------------------
|        Log Transform:         |                              |
|    FLOW-ANNUAL PEAK, CFS      |       Number of Events       |
|-------------------------------|------------------------------|
|  Mean                 2.0191  |  Historic Events          0  |
|  Standard Dev         0.3864  |  High Outliers         0     |
|  Station Skew        -1.0024  |  Low Outliers          1     |
|  Regional Skew        0.1000  |  Zero Events           0     |
|  Weighted Skew       -0.6143  |  Missing Events        0     |
|  Adopted Skew        -0.6000  |  Systematic Events       68  |
|-------------------------------|------------------------------|
```

USGS Station 10359250 FFA Results

```
-------------------------------
Bulletin 17B Frequency Analysis
    09 Apr 2007   09:37 AM
-------------------------------


--- Input Data ---

Analysis Name: 10359250
Description:

Data Set Name: PINE C-WESTWOOD CA-FLOW-ANNUAL PEAK
DSS File Name: C:\Caltrans\Hydrology\REGION6\REGION6.dss
DSS Pathname: /PINE C/WESTWOOD CA/FLOW-ANNUAL PEAK/01jan1900/IR-CENTURY/USGS/

Report File Name:
C:\Caltrans\Hydrology\REGION6\Bulletin17bResults\10359250\10359250.rpt
XML File Name:
C:\Caltrans\Hydrology\REGION6\Bulletin17bResults\10359250\10359250.xml

Skew Option: Use Station Skew
Regional Skew: 0.0
Regional Skew MSE: 0.302
Round adopted skew to nearest tenth

Plotting Position Type: Weibull

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use non-standard frequencies
Frequency: 0.2
Frequency: 0.5
Frequency: 1.0
Frequency: 2.0
Frequency: 4.0
Frequency: 10.0
Frequency: 20.0
Frequency: 50.0
Frequency: 80.0
Frequency: 90.0
Frequency: 95.0
Frequency: 99.0

Round ordinate values to 3 significant digits
Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---


--- Preliminary Results ---

Note: Adopted skew equals station skew and preliminary
frequency statistics are for the conditional frequency curve
because of zero or missing events.
```

```
<< Frequency Curve >>
PINE C-WESTWOOD CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |       0.05       0.95 |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        308         345 |     0.2    |        530        217 |
|        282         311 |     0.5    |        472        202 |
|        260         283 |     1.0    |        426        189 |
|        237         253 |     2.0    |        376        174 |
|        211         222 |     4.0    |        324        158 |
|        172         178 |    10.0    |        251        132 |
|        139         142 |    20.0    |        193        109 |
|         86          86 |    50.0    |        110         68 |
|         48          47 |    80.0    |         61         35 |
|         34          32 |    90.0    |         45         23 |
|         25          22 |    95.0    |         34         15 |
|         13          10 |    99.0    |         20          7 |
|------------------------|------------|-----------------------|


<< Conditional Statistics >>
PINE C-WESTWOOD CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|        Log Transform:        |                              |
|    FLOW-ANNUAL PEAK, CFS     |       Number of Events       |
|------------------------------|------------------------------|
|  Mean                1.9038  |  Historic Events          0  |
|  Standard Dev        0.2799  |  High Outliers         0     |
|  Station Skew       -0.6720  |  Low Outliers          0     |
|  Regional Skew       0.0000  |  Zero Events           1     |
|  Weighted Skew          ---  |  Missing Events        0     |
|  Adopted Skew       -0.6720  |  Systematic Events       22  |
|------------------------------|------------------------------|

<< Conditional Probability Adjusted Ordinates >>

<< Frequency Curve >>
PINE C-WESTWOOD CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |       0.05       0.95 |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        307         --- |     0.2    |        ---        --- |
|        280         --- |     0.5    |        ---        --- |
|        259         --- |     1.0    |        ---        --- |
|        235         --- |     2.0    |        ---        --- |
|        209         --- |     4.0    |        ---        --- |
|        170         --- |    10.0    |        ---        --- |
|        137         --- |    20.0    |        ---        --- |
|         83         --- |    50.0    |        ---        --- |
|         43         --- |    80.0    |        ---        --- |
|         26         --- |    90.0    |        ---        --- |
|         10         --- |    95.0    |        ---        --- |
|        ---         --- |    99.0    |        ---        --- |
```

```
|------------------------|------------|-----------------------|

--- End of Preliminary Results ---



--- Final Results ---

<< Plotting Positions >>
PINE C-WESTWOOD CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|     Events Analyzed      |          Ordered Events          |
|                    FLOW  |       Water       FLOW  Weibull  |
| Day Mon Year        CFS  |  Rank  Year        CFS  Plot Pos |
|--------------------------|----------------------------------|
|  30 Oct 1950         40  |    1   1956        174    4.35   |
|  26 May 1952        154  |    2   1970        156    8.70   |
|  31 May 1953         98  |    3   1952        154   13.04   |
|  08 May 1954         96  |    4   1958        153   17.39   |
|  10 May 1955         24  |    5   1957        143   21.74   |
|  23 Dec 1955        174  |    6   1975        135   26.09   |
|  18 May 1957        143  |    7   1967        122   30.43   |
|  25 Feb 1958        153  |    8   1971        118   34.78   |
|  26 Apr 1959         28  |    9   1974        115   39.13   |
|  20 Apr 1960         33  |   10   1976        105   43.48   |
|  10 May 1961         30  |   11   1953         98   47.83   |
|  07 Apr 1966         66  |   12   1954         96   52.17   |
|  29 Jan 1967        122  |   13   1973         87   56.52   |
|  01 Mar 1968       44.3  |   14   1978         70   60.87   |
|  24 Jan 1970        156  |   15   1966         66   65.22   |
|  26 Mar 1971        118  |   16   1968       44.3   69.57   |
|  27 May 1973         87  |   17   1951         40   73.91   |
|  30 Mar 1974        115  |   18   1960         33   78.26   |
|  15 May 1975        135  |   19   1961         30   82.61   |
|  29 Feb 1976        105  |   20   1959         28   86.96   |
|  01 Jan 1977          0  |   21   1955         24   91.30   |
|  05 Mar 1978         70  |   22   1977          0   95.65   |
|--------------------------|----------------------------------|



<< Outlier Tests >>
---------------------------------------------------------------
<< Low Outlier Test >>
-----------------------
 Based on 21 events, 10 percent outlier test value K(N) = 2.408

             0 low outlier(s) identified below test value of 17

Based on statistics after 1 zero events and 0 missing events were deleted.

-----------------------
<< High Outlier Test >>
-----------------------
 Based on 21 events, 10 percent outlier test value K(N) = 2.408
```

```
           0 high outlier(s) identified above test value of 378
---------------------------------------------------------------


<< Skew Weighting >>
---------------------------------------------------------------
Based on 22 events, mean-square error of station skew =    0.29
Default or input mean-square error of regional skew =     0.302
---------------------------------------------------------------

<< Frequency Curve >>
PINE C-WESTWOOD CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|  Computed   Expected   |  Percent   |   Confidence Limits   |
|   Curve    Probability |   Chance   |       0.05       0.95 |
| FLOW-ANNUAL PEAK, CFS  | Exceedance | FLOW-ANNUAL PEAK, CFS |
|------------------------|------------|-----------------------|
|        302         335 |     0.2    |        508        215 |
|        277         303 |     0.5    |        455        200 |
|        257         277 |     1.0    |        412        188 |
|        234         249 |     2.0    |        366        174 |
|        209         220 |     4.0    |        317        158 |
|        172         177 |    10.0    |        247        133 |
|        139         142 |    20.0    |        191        110 |
|         86          86 |    50.0    |        110         69 |
|         48          47 |    80.0    |         61         35 |
|         34          32 |    90.0    |         44         23 |
|         25          22 |    95.0    |         34         15 |
|         13          10 |    99.0    |         20          7 |
|------------------------|------------|-----------------------|


<< Conditional Statistics >>
PINE C-WESTWOOD CA-FLOW-ANNUAL PEAK
---------------------------------------------------------------
|        Log Transform:         |                             |
|    FLOW-ANNUAL PEAK, CFS      |       Number of Events      |
|-------------------------------|-----------------------------|
|  Mean                 1.9038  |  Historic Events         0  |
|  Standard Dev         0.2799  |  High Outliers        0     |
|  Station Skew        -0.6720  |  Low Outliers         0     |
|  Regional Skew        0.0000  |  Zero Events          1     |
|  Weighted Skew       -0.3431  |  Missing Events       0     |
|  Adopted Skew        -0.7000  |  Systematic Events      22  |
|-------------------------------|-----------------------------|
```

APPENDIX E

Watershed Data Sources

Table E-1. Watershed Data Sources.

Type of Data	Agency/Source	Website
Aerial Photographs (DOQQs)	USGS	http://seamless.usgs.gov/website/seamless/viewer.php
Digital Elevation Model (DEM)	USGS	http://seamless.usgs.gov/website/seamless/viewer.php
Fire History	California Dept. of Forestry and Fire Protection	http://www.frap.cdf.ca.gov/data/frapgisdata/select.asp
Geology Maps	California Geological Survey, USGS	http://www.consrv.ca.gov/cgs/information/geologic_mapping/index.htm
Peak Streamflow Data	USGS	http://nwis.waterdata.usgs.gov/ca/nwis/peak
Precipition-Frequency -- NOAA Atlas 14	NOAA	http://hdsc.nws.noaa.gov/hdsc/pfds/
SSURGO Soils Data	NRCS	http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/
STATSGO Soils Data (statewide)	NRCS	http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/index.html
USGS Quadrangle Maps	USGS	http://seamless.usgs.gov/website/seamless/viewer.php
Vegetation Coverage (Mojave Desert)	Mojave Desert Ecosystem Program	http://www.mojavedata.gov/home.html
Vegetation/Land Use (statewide)	GAP Analysis Project (UCSB, 1998)	http://www.biogeog.ucsb.edu/projects/gap/gap_data_state.html

APPENDIX F

Alluvial Fans: Identification, Evaluation, and Classification

US Army Corps
of Engineers
Sacramento District

DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA

ALLUVIAL FANS IN CALIFORNIA

IDENTIFICATION, EVALUATION, AND CLASSIFICATION

MAY 2000

ALLUVIAL FANS IN CALIFORNIA

IDENTIFICATION, EVALUATION, AND CLASSIFICATION

APPENDIX C

Steps for Identifying, Evaluating, and Classifying Alluvial Fans

MAY 2000

CONTENTS

TABLES

STEPS FOR IDENTIFYING, EVALUATING, AND CLASSIFYING ALLUVIAL FANS

The procedure to identify and classify alluvial fans uses a geomorphic-engineering approach that focuses on landform characteristics and processes. Details of the three-step procedure are provided below, as well as a series of questions to ask when applying the procedure to a specific landform.

THREE-STEP PROCEDURE

Overview

This study used the National Research Council's *Alluvial Fan Flooding* (NRC, 1996), the FEMA's draft *Guidelines for Determining Flood Hazards on Alluvial Fans* (FEMA, 2000), the Flood Control District of Maricopa County's draft manual *Piedmont Flood Hazard Assessment for Flood Plain Management for Maricopa County* (Hjalmarson, 1998), and many other studies, surveys, investigations, and research to provide background for the following three-step procedure.

- Recognize and characterize the type and extent of piedmont landforms.
- Define the nature of the piedmont landform and identify unstable and stable components of the piedmont.
- Identify and apply methods to define and characterize flooding on the piedmont.

The completion of steps 1 and 2 should satisfy the reconnaissance requirements of the Federal Emergency Management Agency's Manual 37 entitled *Guidelines and Specifications for Study Contractors* (1995). The manual states that "when it is determined that an area in a community is subject to alluvial fan flooding, a thorough reconnaissance of the area should be made in order to determine the source of flooding, the apex, the boundaries of the areas, the limits of entrenched channels and the locations of barriers to flow (natural or manmade) that render some areas more flood prone than others, and locations of single- and multiple-channel regions."

Step 1. Recognize and Characterize Piedmont Landforms

Piedmonts are the sloping landforms that typically formed at the base of a mountain or mountain range in states having arid areas such as California. The piedmont landforms generally consist of four major sub-landforms that comprise piedmonts. The four major sub-landforms are relict fans, pediments, alluvial fans, and alluvial plains (Hjalmarson, 1998). Pediments or relict fans are usually formed just below the mountain fronts. Active alluvial fans (fans that are presently aggrading and eroding) can occur anywhere on the piedmont. Alluvial plains are typically formed at the piedmont toe and/or extend below an alluvial fan or bajada (coalescence of alluvial fans).

Nearly all of the streams draining the mountains and piedmonts flow only in direct response to rainfall. Floodwater is typically confined to defined channels of pediments and relict fans. Tributary channels of streams on the pediments and relict fans typically drain to larger throughflow channels. On lower pediment slopes, there may be a transition to alluvial fans or bajadas, and the channels may split and form a network of distributary channels. Inactive fans are common where these distributary channels incised in developed soils and have stable flow paths. Below some mountain fronts and pediments, the flow in channels loses confinement at a topographic break, and active alluvial fans are formed below it (Hjalmarson, 1998). Active alluvial fans are aggrading landforms where sediment is deposited by spreading unconfined floodwater; flow paths may change; and there is sufficient sediment supply from the basin source.

The ability to recognize and identify these landforms based on their distinctive characteristics is essential for flood plain managers, engineers, and planners. These landforms can be reliably identified using several combined criteria (NRC, 1996; Hjalmarson, 1998). Active alluvial fans are landforms that pose great flood hazards, and they are the primary focus for this study. In this study, characteristics of similar landforms are briefly discussed so that they can be recognized with respect to both their similarities and differences.

Relict Fans. A relict fan is an erosion remnant of an old alluvial fan that was formed in a past geologic epoch and hardened by cementation. A relict fan is a landform that has survived decay or disintegration such as an erosion remnant or that has been left behind after the disappearance of the greater part of its substance (NRC, 1996). Many relict fan areas are the remaining parts of larger landforms that have eroded away or have been partially buried and may have many inset alluvial fans. Characteristics of relict fans are typically incised channels in cemented conglomerates of cobbles and boulders, and drainage typically is tributary, but small pockets of distributary channels may occur. Some relict fans have ridge-valley morphology. Incised throughflow streams on relict fans typically are between 10 and 20 feet deep with steep banks. Desert pavement and rock varnish are common on flat interfluves on relict fan, and the general slope is typically 1 to 6 percent. Relict alluvial fans are typical below a mountain front. Inset alluvial fans are generally small and confined between relict fan remnants. Fluvial deposits on inset alluvial fans can act like a flood plain with high potential for scour and fill. Much of the alluvial fan material may be from gullying of the relict fan, and such material may be bouldery (Hjalmarson, 1998).

Pediments. Pediments are developed on bedrock and are formed by weathering and erosion. They may resemble inactive alluvial fans and relict fans largely because the surface of pediments can be covered with sand and gravel a few inches to a few feet thick. For the purpose of identifying the landform, a pediment is where there are bedrock exposures, even if the exposures are scarce along incised channels. Most of the surface material at the pediment toe is coarse sand from the weathered granite. The toe of the pediment is where the bedrock is sufficiently covered by fluvial material and/or weathered granite that is not visible along eroded channel banks and where there are no large boulders on the land surface. Many relict fans and pediments have similar flood characteristics. For example, they both typically have tributary drainage patterns, and the 100-year flood is confined to defined channels and adjacent land. Characteristics of pediments are incised channels generally formed in bedrock and old soils; drainage typically is tributary but distributary channels may be present especially on lower slopes; there are many first order tributary channels; parent rock typically is granite with large granite boulders on the upper slopes near the mountains; the crests of transverse slopes are small and shoulders are steep; and the general slope typically is 2 to 5 percent (Hjalmarson, 1998). Detailed characteristics of relict fans and pediments are discussed in *Piedmont Flood Hazard Assessment for Flood Plain Management for Maricopa County, Arizona* (Hjalmarson, 1998).

Alluvial Fans. An alluvial fan is defined as "*a sedimentary deposit at a topographic break, such as the base of a mountain front, escarpment, or valley side, that is composed of fluvial and/or debris flow sediment and which has the shape of a fan either fully or partly extended*" (NRC, 1996).

Alluvial fans are gently sloping, cone or fan-shaped landforms common at the base of mountain ranges in arid and semi-arid regions such as the western United States. There are many alluvial fans throughout California, Nevada, Arizona, Montana, Utah, Colorado, New Mexico, Wyoming, Oregon, and Washington. These landforms are deposited with alluvium. The lack of vegetative protection in dry lands allows infrequent, heavy rains to flush large amounts of rock debris down slopes. It is this transported sediment material or alluvium that makes up an alluvial fan. The coarsest debris is deposited first closest to the canyon mouth as the streams spread out and lose their conveying energy while the slope become smoother and flatter. Finer sediments are transported farther and deposited at a greater distance from the fan apex. Materials ranging from sands and gravel to large boulders can be transported downhill by water, deposited, and scattered all over the fan surface.

Results of the survey of counties in California indicated that there are many active alluvial fans, either totally or in part, in a number of counties. Also, many alluvial fans in part of California have reached the inactive stage because no evidence of flooding, erosion, or channel movement have ever been observed. The following are general characteristics of alluvial fans (NRC, 1996; FCDMC 1998). Following the definition, geomorphic characteristics are discussed in detail. These characteristics are used to define the stable and unstable areas of an alluvial fan, and classify alluvial fans based on their geologic age and past hydraulic activities.

Composition. An alluvial fan is a sedimentary deposit of loose, unconsolidated or weakly consolidated sediments which have been deposited during the Quaternary period. The investigator can use geologic maps to determine if the soil is alluvium. Modern sedimentary deposits are shown in yellow on geologic maps and typically labeled "Qal," which represents Quaternary alluvium. The Natural Resources Conservation Service (NRCS) soil maps can also be used to determine the landform. In addition, the U.S. Department of Agriculture, Soil Conservation Service, and the U.S. Geological Survey have soil surveys and maps which can be used to identify the landform. Most importantly, field reconnaissance is recommended for verifying a sedimentary deposit.

Shape. Alluvial fans are landforms that have the shape of a fan either partly or fully extended. Modern and old flow paths on these fans radiate outward to the perimeter of the fan terminus or toe. Old flow paths can be eroded away or erased by wind, rain, and sheet flow. Young alluvial fans typically are convex upward in the transverse direction. The transverse convexity can be eroded away on older alluvial fans or lost by coalescence with adjacent alluvial fans (Hjalmarson, 1998). Topographic maps can be used to identify the criteria.

Topographic Break. Alluvial fans are located at a topographic break. The topographic apex is the location or point where long-term channel migration and sediment accumulation become noticeably less confined than upstream of the break. It is this focal point where the stream widens and corresponding flow depths decrease, resulting in less sediment transporting power. The topographic apex is the head or highest point on an active alluvial fan. The hydrographic apex is the highest point on an alluvial fan where flow is last confined (NRC, 1996). It may be at or downstream of the topographic apex. Below these apexes, flow becomes less confined and is able to migrate more freely. Less confinement may lead to greater channel widths and smaller channel depths. As a result, sediment deposition increases, and flow paths become more unstable (NRC, 1996).

Boundaries. Boundaries of an alluvial fan consist of distal terminus, or toe, and lateral boundaries. The distal terminus, or toe, of an alluvial fan ordinarily is defined by an intersecting stream usually at the downstream of a fan, a playa lake, an alluvial plain, or a smoother, gentler slope of a piedmont plain. Lateral boundaries of alluvial fans are the edges of deposited and reworked alluvial materials. The lateral boundary of a single alluvial fan typically is a trough, channel, or swale formed at the lateral limits of deposition. In the case of multiple fans that coalesce to form bajadas, where deposits and reworked material of adjacent alluvial fans merge, the lateral boundaries are generally marked by a topographic trough or ridge (NRC, 1996). It is recommended that soil and topographic maps and available aerial photographs be used together as a mean to identify alluvial fans and their boundaries.

Alluvial Plains. Many alluvial fans, in particular the lower portions of alluvial fans or at piedmont toes, coalesce into a generally smooth and nearly level surface called an alluvial plain. An alluvial plain is a very low gradient fan delta built onto the basin floor flood plain or a relict flood plain of a base level stream. The upper and lower boundaries of alluvial plains can be indistinguishable with intricately mixed sediment from upper areas of the piedmont and base level stream. Precise boundaries are not necessary for flood hazard definition because the flood hazard of alluvial plains, adjacent alluvial fan toes, and adjacent flood plains of base level streams are typically from shallow floodwater except where there is channel incision from lowering of the base level stream (Hjalmarson, 1998). Distinguishable characteristics of an alluvial plain are aggrading or rather stable fluvial deposit with little transverse relief and small channels; channels typically less than 1 foot deep; few tributary channels on the surface; little, if any, rock varnish but possibly some desert pavement; channel incision of a few feet where there has been general headcutting of base level stream; and general slope of 0 to 3 percent.

Step 2. Determine the Activity and Stability of the Piedmont Landform

Flood hazards on piedmont landforms relate to relict fans, pediments, alluvial fans, and alluvial plains. Nearly all of the streams draining the mountains and piedmonts flow in direct response to rainfall. The floodwater on pediments and relict fans is typically confined to defined channels. Tributary channels on pediments and relict fans typically drain into larger throughflow channels. These throughflow channels are well defined and stable. On lower pediment slopes, there may be a transition to alluvial fans or bajadas, and the channels may split and form a network of distributary channels. Many of these distributary channels are incised in developed soils and have stable flow paths. Below some mountain fronts, pediments, and relict fans, the flow in channels loses confinement, and active alluvial fans are formed. The flood hazards associated with these landforms are broadly classed as areas with either stable (inactive) or unstable (active) flow paths. Stability is the indicator of the magnitude of hazard on the landform. This study focuses on alluvial fans, especially the active parts of fan. Step 1 should aid in differentiating and selecting only alluvial fans for analysis in Step 2. This step uses geomorphic and weathering characteristics, and geologic age to determine whether the alluvial fan is active or inactive.

Activity. Generally, there are two types of alluvial fans. An alluvial fan can be described as active or inactive based on its geomorphic and weathering characteristics, geologic age, and hydraulic activity. Many alluvial fans have both active and inactive areas. "Most alluvial fans have parts that are active and parts that are inactive. Alluvial fan flooding occurs only on active parts of alluvial fans. It is important to identify both active and inactive parts of the fan, because this provides a map of where flooding can occur as well as where it probably will not occur" (NRC, 1996). The term "active" refers to that portion of a fan where flooding, deposition, and erosion are possible. If flooding and deposition have occurred on part of an undeveloped fan in the past 100 years, clearly that part of the fan is active. If flooding and deposition have occurred within the past 1,000 years (during the Holocene epoch), that part of the fan can be considered to be active (NRC, 1996). Documented records of past flooding and debris flow on fans indicate an active alluvial fan. One can start to examine the historical record of flooding and sedimentation. Aerial photographs from different years can be compared to identify recent deposited materials and any changes or movement of channel geometry. A geomorphic map of the fan surface is important for determining where active deposition and erosion have occurred.

In developed areas, however, the validity of using the past 100 years for determining what is an active versus inactive fan is heavily influenced by man's activities. For example, Sacramento County is located on a large alluvial fan, and levees and other flood control measures have been in place or under construction along the rivers and streams in the county since the 1860's. The Sacramento area is now highly urbanized, and the alluvial fan is considered as inactive because these flood control measures and urbanization preclude changes in natural drainage and mass flooding. In this way, potential flood risks from alluvial fan flooding are reduced or eliminated in the Sacramento area.

Active Fans. Significant characteristics of an active alluvial fan are fluvial deposits with no or very little carbonate development; fan shaped in plan view with the hydrographic apex at the topographic break; typically no desert varnish; wide stream channels with little incision (width-to-depth ratio is usually greater than 40 at bank full stage) or very small channels (general slope between 1 and 10 percent). Deposition, erosion, and unstable flow paths are possible, hydraulically, for active areas of alluvial fans. Active alluvial fan flooding is characterized by flow path uncertainty so great that this uncertainty cannot be set aside in realistic assessment of flood risk or in the reliable mitigation of the hazard (NRC, 1996).

Inactive Fans. Significant characteristics of an inactive alluvial fan are fluvial deposits with carbonate development; generally fan shaped with distributary network of incised channels; flat transverse slopes of interfluves; interfluves typically drained by small channels that are tributary to throughflow streams; stable interfluve slopes and throughflow streams typically incised; general slope typically between 1.5 and 4 percent (Hjalmarson, 1998). Hydraulically, flows are confined within incised channels, with minimal deposition and erosion of channel beds and banks. Inactive alluvial fan flooding is characterized by flow paths with a higher degree of certainty in realistic assessments of flood risk or in the reliable mitigation of the hazard (FEMA, 2000).

Stability. There are several indicators that can be used to verify soil stability on piedmont landforms. They include soil surface textures and colors, soil development profiles, vegetative species, and geologic age of the landforms.

Stable Areas. Stable areas include most hillsides and defined channels of relict fans, pediments, and inactive alluvial fans. Flow paths of stable areas are predictable using geomorphic methods based on channel shape, surface geology, soil development, and landform morphology. Flood boundaries for these stable areas are predictable using classic engineering methods based on hydraulic factors of roughness, grade, and channel cross-sectional geometry. Stable areas also include sheet flow and many split flow areas. These split flow areas may have an uncertain distribution of flow where the hydraulic geometry, grade, and roughness are relatively stable, but small obstructions or small amounts of scour or fill associated with the generally shallow flow depths can alter the distribution of floodflow (Hjalmarson, 1998).

Visible soil carbonate formation is a good indicator of an older stable surface. A well-developed soil with dark brown or reddish-brown sandy clay loam or clay texture a few inches below the surface is also a good indicator of a stable landform. Older stable surfaces are characterized by very smooth, dark surfaces and usually have a well-developed tributary drainage network conveying flows into throughflow channels. Throughflow channels are mostly stable tributary and distributary flow paths with channel incision usually greater than 3 feet (Hjalmarson, 1998). Surface areas covered with scattered large trees or mature vegetative communities, which include slow-growing species such as paloverde, ironwood, mesquite, and cacti, also indicate a stable landform (NRC, 1996; Hjalmarson, 1998). Stable channel banks must exist for an extended period of time for the trees to grow and nourish. The trees would be washed away and not reach maturity if the flow paths are unstable and have moved or changed quite often. Other characteristics indicating stable soil surfaces include no recent deposition of sediment; no debris flow or mudflow on the landform; no channel movement or formation of new channels; adequate channel capacity to convey the 100-year flow; and large alluvial fan relative to the size of the drainage basin. The width-to-depth ratios are usually less than 40 at bank full stage for most stable channels. These characteristics can be analyzed by comparing old and recent aerial photographs and topographic maps, and documented reports of flooding.

Unstable Areas. Unstable areas have uncertain flow paths. This uncertainty "is so great that this uncertainty cannot be set aside in realistic assessments of flood risk or in the reliable mitigation of the hazard" (NRC, 1996). Areas of flow path uncertainty and boundaries for these areas are predictable using geomorphic methods. Flow paths on piedmonts that are considered unstable typically do not have the characteristics of stable areas. An area is considered unstable if there is documented movement, abandonment, or formation of new channels based on comparing recent aerial photographs, land surveys, and topographic maps with old ones.

An unstable surface is geologically very young (less than 10,000 years old) as compared to an older stable surface (greater than 10,000 years old). Some reliable indicators of a young surface are: (1) the lack of developed soil as indicated by little oxidation or reddening in the upper few inches, (2) the absence of surface weathering on non-granite landforms as indicated by the lack of desert pavement and rock varnish, and (3) the presence of throughflow channels and banks that are perched above the adjacent land when viewed across the channel profile (Hjalmarson, 1998).

Several indicators are needed to verify flow path instability. A single indicator such as the lack of desert varnish may also indicate an eroding surface where the stones have washed away by sheet floods. Other less reliable but useful indicators of unstable flow paths are: (1) throughflow channels with large width-to-depth ratios, typically more than 50, that are characteristic of channels formed in non-cohesive material, (2) estimated 100-year flood overflows the banks of throughflow channels and inundates much of the landform including many of the ridges and interfluves separating the channel, and (3) scattering of large trees such as paloverde over the landform with the absence of distinctly abundant trees along the banks of throughflow channels (Hjalmarson, 1998). **Table C-1** shows selected characteristics of stable and unstable flood hazard areas of piedmont landforms.

Geologic Age. A variety of characteristics can be used to separate deposits of different age. These include fan surface morphology and sediment weathering. In general, the surface of a recent deposit typically is irregular and has a light color, whereas older deposits generally are smoother due to prolonged weathering, which causes the natural wear and tear of material features. As deposits weather, fragments become smaller, and edges of deposits from individual episodes become more typical. Older alluvial fan surfaces are characterized by very smooth, dark surface dissected by narrow channels.

Table C-1. Selected Characteristics of Stable and Unstable Flood Hazard Areas of Piedmont Landforms.

Landform	Component Landform	Significant Stability, Geometry, and Flood Characteristics*
Relict fan	Erosional fan remnant (stable)	• Remnants of broad coalescent plains or bajadas that have been incised by streams for thousands of years. • The presence of large areas of varnished desert pavement suggests the surface of this landform is very stable in many places and floodflow has been conveyed past these stable areas for thousands of years. • The 100-year flood is confined to throughflow channels and small overbank areas adjacent to the defined channels.
	Inset alluvial fan (unstable)	• Generally small and confined between relict fan remnants. Unstable bouldery fluvial deposits can have a great aggradation and erosion potential. • The 100-year flood can spread over much of these areas.
Pediment	Bedrock remnant (stable)	• Nearly all of these landforms are eroding and stable. • Relatively small areas along larger channels are subject to scour and fill. • The 100-year flood typically is confined to defined channel of throughflow streams and streams that head on the pediment.
	Inset alluvial fan (unstable)	• These fluvial deposits resemble small flood plains except the inset fan may be subject to more erosion and deposition than typical flood plains. • Inset deposits of sediment can be the apex of distributary channels.
Alluvial Fan	Active alluvial fan (unstable)	• Fluvial deposits with little or no carbonate development, no insitu rock varnish development, and seldom any desert pavement. • The surface typically is a light tan or gray color that is indicative of recent abrasion of the weathered surface during sediment transport. Some areas not recently eroded or that have received sediment may be darkened by weathering. • Typical channels are poorly defined with large width-to-depth ratios (> 50) and may have a braided pattern in addition to a general radiating pattern below the hydrographic apex. • Typical clasts are angular, sorted, and unweathered. Both the maximum and average clast size of the sediment deposits decreases rapidly downfan. • Deposits are mounded across the fan unless there has been erosion and/or confluent with adjacent alluvial fans. • General slope 1-10 percent
	Inactive alluvial fan (stable)	• Fluvial deposits with well carbonate development. • Reddening of upper soil horizon, development of desert pavement, and desert varnish on exposed rock litter. • Well-incised throughflow channels, trees along the throughflow channels, and developed tributary drainage systems that head on the fan surface. • No evidence of recent sediment deposition on the fan surface, and no recent debris flow activity below the geologic apex. Any debris flow activity is confined to the mountain slope. • The channels and/or overbank capacity is adequate for the 100-year flow. • Bedrock outcrops in or between channels.
Alluvial Plain	Piedmont toe (generally stable but some areas may be unstable)	• Rather stable or possibly aggrading fluvial deposit with little transverse relief except where channels are incised due to lowering of base level stream. • The 100-year floodwater may spread over large areas. • Areas with low slopes, lack of flow confinement, little aggradation, and developed caliche soil that resists erosion is stable. Areas may be unstable where there is much aggradation. • Where channels are incised, the gully walls may be unstable, and headcutting may progress upslope.

*Desert pavement, desert varnish, and calcic horizon are found mainly on alluvial fans in desert environments.

Source: Hjalmarson, 1998 (use with permission).

Based on the examination of these characteristics, a geomorphic map of the alluvial fan surfaces can be assembled and classified into different age categories. These age categories can be from as old as middle Pleistocene (about 2 million to 10,000 years ago) to as young as late Holocene (the past 10,000 years). Eight characteristics, identified by Christenson and Purcell (1985), are useful in separating alluvial fan deposits into the three general age categories. However, it is important to note that these characteristics are based on arid desert environments. As a result, some of these characteristics do not apply to alluvial fans in non-desert and coastal environments. This is especially true in areas where chemical weathering is more common than mechanical weathering. **Table C-2** shows the eight characteristics and the nature of each for the age categories. A brief discussion of each characteristic follows the table.

Table C-2. **General Characteristics of Young (<10,000 to 15,000 years), Intermediate (10,000 to 700,000 years), and Old (>500,000 years) Alluvial Fan Deposits.**

Characteristic	Young	Intermediate	Old
Drainage pattern	Distributary; anastomosing or braided	Tributary; dendritic	Tributary; dendritic or parallel
Depth of incision	Less than 1 meter	Variable (1 to 10 meters)	Greater than 10 meters
Fan surface morphology	Bar and channel	Variable, generally smooth and flat	Ridge and valley, most of surface slopes
Preservation of fan surface	Currently active	Incised, but well-preserved wide, flat divides	Basically destroyed, locally preserved on narrow divides
Desert pavement*	None to weakly developed	None to strongly developed	None (surface destroyed) to strongly developed (surface preserved)
Desert varnish*	None to weakly developed (most varnished clasts reworked from older surfaces or bedrock)	None to strongly developed	None (surface destroyed) to strongly developed (surface preserved)
B horizon	None to weakly developed	Weakly to strongly developed	None (surface destroyed) to strongly developed (surface preserved)
Calcic horizon*	None to weakly developed, carbonate disseminated throughout	Weakly to strongly developed	None, carbonate rubble on surface (surface destroyed) to strongly developed petrocalcic horizon (surface preserved)

*Characteristic applies mainly to alluvial fans in desert environments. Source: Christenson and Purcell, 1985.

Drainage Pattern & Drainage Basin. Active alluvial fans have a light surface with a braided, radiating, bifurcating and/or distributary drainage patterns indicating young surfaces that have been recently erode or subject to sediment deposition and aggradation. Primarily, the braided system consists of interconnected distributary channels formed in depositional environments. The depth of incision of drainage is generally less than 3 feet, and major runoff events generally flood the fan surface. The channel bed composition can vary and include silt/clay, sand, gravel, cobbles, and other debris deposits. A tributary drainage pattern is characteristics of older fans or pediments. These older fans usually have an incised dentritic or parallel drainage pattern with a dark surface of desert varnish. Older alluvial fan deposits are undergoing degradation; thus, channel incision depth generally increases with age. Correspondingly, the depth of incision depends on the size of the drainage basin and the size of fan.

"The braided channel system is characterized by high bank erosion rates, excessive deposition occurring as both longitudinal and transverse bars, and frequent shifts of the bed locations. Bed morphology is characterized by a closed spaced series of rapids and scour pools formed by convergence/divergence processes that are very unstable. The channels generally are at the same gradient as their parent valley. A combination of adverse conditions are responsible for channel braiding, including high sediment supply, high bank erodibility, moderately steep gradients, and very flashy runoff conditions which can vary rapidly from base flow to an over-bank high flow on a frequent basis" (Rosgen, 1996). Characteristic width-to-depth ratios are very high, exceeding values of 40. The general slopes range from 2 to 4 percent and greater. The capacities of these distributary channels usually decrease in the downstream direction.

Active alluvial fans are typically associated with debris and sediment supply. Primarily, there are two major sources of material that make up an active alluvial fan. First, the source of material is derived from sediment production in the mountainous drainage basin. Loose and unconsolidated debris usually accumulates along the beds and banks of stream channels until a large flood transports the debris onto the alluvial fan. Second, the material is derived from channel incision and/or headcutting into relict fans during runoff, sometime referred to as channel alluvial accumulation. This channel alluvial accumulation accounts for 80 to 90 percent of the volume of significant mudflows (Williams and Smith, 1990). The source of this material is below the mountain front and commonly between the topographic and hydrographic apexes (Hjalmarson, 1996). Deposited sediment is re-mobilized and re-deposited down the fan by subsequent floods. The flow paths may change during flooding as a result of sedimentation and erosion. Another important factor of an active alluvial fan is the relative size of the drainage basin to the size of the alluvial fan. Although watershed size may have a significant role in the total accumulation of material in the channel bottom, the process may take a very long time. Researchers found that fans with relatively large drainage basins were more active than fans with relatively small drainage basins (Hjalmarson, 1996).

Depth of Incision. The depth of channel incision is usually less than 3 feet for young alluvial fan deposits. These channel incisions are subject to future erosion and deposition on active alluvial fans. The channels can be filled with sediment; new channels can be formed; or existing channel banks can be shifted, expanded, or remobilized. Characteristic width-to-depth ratios usually exceed values of 40 for channels on active alluvial fans.

Relict and inactive fans usually developed well-incised and stable throughflow channels over the long period of repeated flood episodes. Trenching at the fan head or even over the entire fan may occur as a result of channel incision of older fan deposits, either because the sediment supply has diminished or because the transport capacity has increased due to climate or vegetation changes within the source basin, or to tectonism (NRC, 1996). These channels are well incised and usually have adequate rainfall-runoff conveying capacity for the 100-year flow. The depth of incision for these channels ranges from about 3.3 feet to greater than 33 feet for intermediate to a very old relict fan. Characteristic width-to-depth ratios are smaller than those of active alluvial fans. They are usually less than 40 width-to-depth ratios.

The entrenchment ratio can also be used as an indicator of channel stability. An entrenchment ratio of 1.4 or less indicates a stable channel, while a ratio greater than 1.4 indicates an unstable channel. Entrenchment ratios of an active alluvial fan increase gradually from the apex out onto the fan as the channels become shallower and wider where flows become unstable.

Fan Surface Morphology and Vegetation. A young, active surface is typically bar and channel with rarely any mature vegetation. Recently deposited alluvial soil contains little organic carbon or clay, is low in nutrients, and has little water holding capacity (NRC, 1996). A typical active alluvial fan has uniform immature vegetation communities consisting mainly of annual, quick growing plants and grasses which occur usually after the rainy season. However, desert trees and bushes can be scattered on active alluvial fans, suggesting the absence of stable flow paths. Generally, the surface of an intermediate alluvial fan is smooth and flat, but can be bouldery, well armored, and well preserved. For old alluvial fans, most of surface slopes are ridges and valleys of well-incised throughflow channels, and most of the fan surface may have been destroyed. Saguaro cacti, cholla, Palo Verde, and creosote bush are seldom on very active alluvial fans and are typically on old surfaces of relict fans and pediments (NRC, 1996; Hjalmarson, 1998). Vegetation is limited on old surfaces because they receive only direct rain and are subject to erosion and because the soil can be less fertile due to the carbonate development on the surfaces. The use and interpretation of vegetation on alluvial fans must be specific to the individual fan (NRC, 1996).

Preservation of Fan Surface. Intermediate age alluvial fan surfaces are normally incised but well preserved, whereas young alluvial fan surfaces are continuously reshaping through the processes of erosion and aggradation. For an old fan, the entire surface may be destroyed due to the prolonged weathering processes. Some areas of the surface, however, may be locally preserved on narrow divides.

Desert Pavement. Desert pavement is "surfaces of tightly packed gravel that armor, as well as rest on, a thin layer of silt, presumably formed by weathering of the gravel. They have not experienced fluvial sedimentation for a long time, as shown by the thick varnish coating on the pebbles, the pronounced weathering beneath the silt layer, and the striking smoothness of the surface, caused by obliteration of the original relief by downwasting into depression" (NRC, 1996). Desert pavement, a concentration of pebbles and cobbles on the land surface, is best seen in the field and is indicative of old surfaces formed by the removal of fine-grained material by wind, soil creep, and sheet flow. Pavement can sometime form on young coarse-grained alluvial fans (Christensen and Purcell, 1985). Thus, pavement development is not always a reliable indicator of surface age and type of landform. However, most active alluvial fans and stream channels that are prone to flooding typically do not have desert pavement. The identification of active or inactive surfaces is reliable when several identifiers point to a particular type of landform.

Desert Varnish. Desert varnish is "a dark coating (from 2 to 500 microns thick) that forms on rocks near the Earth's surface as a result of mineral precipitation and eolian influx. The chemical composition of rock varnish typically is dominated by clay minerals and iron and/or manganese oxides and hydroxides, forming red and black varnishes, respectively. With time, the thickness or the coating increases if abrasion and burial of the rock surface do not occur. As a result, clastic sediments on alluvial fan surfaces that have been abandoned for long periods of time have much darker and thicker coatings of varnish than do younger deposits" (NRC, 1996). Desert varnish is one of the best indicators of surface stability and the age of alluvial fans. It is easily observed and reliable. Dark brown and blackish layers of clays and manganese and iron oxides form on the surface of stable rocks over thousands of years. The dark appearance of rock varnish is not precisely indicative of age, but the presence of rock varnish on the landform is indicative of old surfaces such as those of relict fans.

B horizon. A mineral horizon of a soil, below the A horizon, sometimes called the zone of accumulation and characterized by one or more of the following conditions: (1) accumulation of clay, sesquioxides, humus, or a combination of these; (2) prismatic or blocky structure; (3) redder or browner colors than those in the A horizon; or (4) a combination of these. Generally, there is none to weakly developed B horizon on active alluvial fans. It is commonly found on older alluvial fan surfaces, generally within the first foot of depth. For some old inactive alluvial fans, there is no B horizon because the surface was destroyed due to the eroding and weathering processes.

Calcic Horizon. Calcic horizon is "a secondary calcium carbonate accumulation in the lower B horizon that occurs as coating on clasts and as lenses in fine-grained sediment matrices; it is at least 6 inches thick and contains 15 percent or more calcium carbonate" (NRC, 1996). The carbonate on active alluvial fan surfaces is none to weakly developed. The presence of carbonate on alluvial fan surfaces indicates old and stable surfaces.

Step 3. Apply Methods to Define the Flooding Classification on the Alluvial Fan

Step 3 is the selection and application of methods to define (predict) the nature and location of flooding on alluvial fans. A detailed theoretical analysis of alluvial fan flooding is not the intent of this study. However, a general discussion of methods that can be used to define the flood hazards is appropriate. Conceptually, there are three categories of alluvial fan flooding: (1) clear water flows that can be analyzed using traditional hydraulic methods, (2) hyper-concentrated sediment flows that can be analyzed by sediment transport theory, and (3) debris flows that can be analyzed by various empirical methods such as the bulking factor, the Bingham models, and other methods. The choice of methods is directly related to the type of fan to be evaluated.

Inactive Alluvial Fans. For inactive fans where flow paths and flood boundaries are stable and predictable, traditional engineering modeling can be used to compute water-surface profiles and define the 100-year flood. An inactive fan with flooding indicates that the area is subject to riverine flooding.

Traditional Models. For stable areas on a fan, standard hydraulic engineering methods such as backwater computations can be used to determine the depths, flow distributions and splits, velocity, and extent of the 100-year flood. Using traditional engineering methods, a flood event probability is estimated, and then elevations and flood boundaries can be computed.

HEC-HMS is a hydrologic modeling system capable of simulating rainfall-runoff modeling. The program can be used to predict flood flow data at the watershed mouth or fan apex to determine the 10-, 50-, 100-, and 500-year peak flows if streamflow records are not available. HEC-RAS is a river analysis system. The model is appropriate for delineating stable distributary channels on stable and/or inactive alluvial fans. The model can be used to calculate water surface profiles for steady gradually varied flow. The model can handle a full network of channels, a dentritic system, or a single river reach. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles. The effects of obstructions such as bridges, culverts, weirs, and structures in the flood plain may be considered in the computations. However, a great number of channel cross sections may be required to accurately compute the backwater profiles. In addition, an investigator has to use sound judgement in determining the flow splits among the various distributary channels. Each split channel must be considered as a separate reach, and an estimate of the most probable flow in the channel must be assumed and/or assigned. A rating method can be employed to determine the correct flow in each channel. The disadvantage of this method is that the assumptions of channel stability, friction, flow distributions and losses, and flow-path locations may be severely limited. Hydraulic models by USGS, NRCS, and other methods may also be used for inactive alluvial fans. A hydrodynamic model such as FLO-2D may also be used for some areas on inactive fans.

Active Alluvial Fans. For active fan areas where flow paths are unstable and unpredictable, the flood hazard is assessed using geomorphic evidence and possibly supplemented with engineering modeling. Since the frequency and extent of flooding on active fans cannot be determined exactly, the status of existing or planned development in the area is also a major concern and is considered in Step 3 for active fans.

Geomorphic Evidence. Using geomorphic evidence is preferred for unstable areas where there are changes in channel conditions; fan surface changes during flooding due to scour or fill; and flow path movement below the hydrographic apex. The major advantage of using geomorphic evidence is that it is physically and process-based. This method is superior to traditional engineering methods for delineating flood hazards on active alluvial fans because the magnitude of the 100-year flood peak discharge is not the only important factor of the hazard. Other factors are (1) large volume of debris and sediment in the floodwater, (2) changing flow paths due to sedimentation and erosion, (3) unconfined floodwater that may spread in various flow paths at uneven distributions, and (4) movement of sediment by subsequent floods. The hazard within an active alluvial fan boundary is severe and dangerous due to sedimentation, erosion, and avulsion. Thus, it is reasonable to assume that an active alluvial fan is subject to flooding over the entire fan. Traditional engineering methods may not be able to predict a reliable and realistic flood condition on active alluvial fan surfaces because of these factors. Therefore, it is important to delineate the active alluvial fan areas using geomorphic evidence as described in Steps 1 and 2, possibly supplemented with traditional engineering models.

Risk-Based Analysis. The National Research Council (NRC, 1996) recommended consideration of the use of *Guidelines for Risk and Uncertainty Analysis in Water Resources*

Planning (USACE, 1992) for specific guidelines on how to apply method for analyzing active alluvial fans. The principles of risk-based analysis provide a framework for a more general and realistic way to identify areas subject to active alluvial fan flooding.

FAN Program. FEMA has issued a draft *Guidelines for Determining Flood Hazards on Alluvial Fans* dated February 23, 2000. These guidelines include an alluvial fan modeling program entitled "FAN". As a supplement to using geomorphic evidence, this program can be used to evaluate fully active conical-shaped alluvial fans.

FLO-2D. For more complex as well as simple systems, the FLO-2D can be used to predict the flow depths and flow boundaries on active alluvial fans, urbanized alluvial fans, or regions that are not cone- or fan-shaped. FLO-2D is a two-dimensional, finite difference, flood routing model which can simulate clear water, mud, and debris flooding over unconfined alluvial fans and flood plains. It is a physical, process-based model which routes flood hydrographs and rainfall-runoff using a diffusive wave approximation to the momentum equation. It has a sediment transport component and can compute sediment deposition and erosion. Debris and sediment can be bulked to simulate realistic flow conditions. FLO-2D can be used to investigate the possible effects of channel incision, avulsion, blockage, channel bank failure, and debris deposition on fan surfaces with complex topography and roughness. Split flow, shallow overland flow, and flow in multiple channels can be modeled. In urbanized areas, the effects of flow obstructions such as buildings and other manmade structures, which limit storage or constrict flow paths, can be simulated. The process-based FLO-2D is practical for delineating debris flow fans because of the multifunctional capability of the program. It should be noted that there are other computer models available, however, the Corps of Engineers considers this program to be reliable for most alluvial fan modeling problems. Using FLO-2D in combination with geomorphic evidence may result in more reliable and realistic natural flood conditions on active urbanized alluvial fans.

Combination. Flexibility in choosing an appropriate method to delineate an active alluvial fan is necessary since there is no clear analytical technique for evaluating and estimating the spatial extent of its flood hazards. Site-specific evaluation is very important since the characteristics of two fans are often quite different. The analytical process requires knowledge and the ability to apply judgement regarding the hydraulic analyses and qualitative interpretations of geologic evidence concerning the recent history and probable future evolutions of channel forms, as well as flooding and sedimentation processes. For that reason, the combination of engineering models and geomorphic evidence may provide a more reliable approximation of hazard boundaries.

Existing or Planned Development. Since flood damages and loss of life are possible anywhere on an active alluvial fan, the area must be planned, managed, and regulated based on the degree of development in the area. For that reason, Step 3 also includes a determination of the extent and type of development on the active alluvial fan.

APPLICATION OF THREE-STEP PROCEDURE

Based on the three-step procedure, the following types of questions can be asked to help identify and characterize an alluvial fan. Possible sources of information and procedures to answer each question are also included.

Step 1. Determine whether the landform is an alluvial fan

Is the landform a sedimentary deposit composed of alluvium or debris-flow deposits?

- Use geologic and soil maps.
- If maps are not readily available, field investigation is the best alternative.

Does the landform have the shape of a fan?

- Use topographic maps.
- Use aerial photographs.

Is the landform located at a topographic break?

- Use topographic maps.
- Use aerial photographs.

Where are the lateral boundaries and terminus or toe of the fan?

- Use topographic and soil maps as well as aerial photographs.
- Field check.

Step 2. Determine the parts of fan that are active and/or parts of fan that are inactive

Is there any historical record of flooding on the fan or parts of the fan?

- Check with local flood control agencies, departments of public works, or local authorities for any debris flow or mudflow event that has occurred in the recent past.
- Check for flooding events including the possibility of scour and erosion of the channel beds/banks along the fan starting from the fan apex.

- Check for records of flood damages including structural damages as well as any loss of property or human life.

What is the overall depth of incision of the throughflow and local channels?

- Use topographic maps and conduct fieldwork to determine the depth of incision (less than 2 feet, varying depths among channels between 3 feet to 10 feet, or greater than 10 feet).

- Determine the degree of incision of throughflow and local channels, and rate the alluvial fan age based on this estimation (Table C-2).

- Determine the width-to-depth ratios of channels on the fan (less than 40 indicates stable channel, and greater than 40 indicates unstable channel); or

- Determine the entrenchment ratio of the throughflow channels (less than 1.4 indicates stable channel, and greater than1.4 indicates unstable channel).

Note: Channels at or just below the fan apex can be well entrenched and very stable, but entrenchment ratio may increase significantly down the fan, and channels may become very unstable.

Are there any changes in flow path movement?

- Aerial photographs - compare recent aerial photos with old ones for any changes in flow paths or any new flow paths that may have been created recently.

- Topographic maps - field check for any significant changes from available topographic maps.

What is the fan surface morphology?

- Topographic maps and fieldwork - determine the fan surface (bar and channel, smooth and flat or bouldery, deeply dissected surface, and/or depositional features).

- Aerial photos and fieldwork - determine the preservation of fan surface and vegetative communities or species.

- Aerial photos and fieldwork - determine the development of desert pavement and desert varnish on the fan surface (none, weak, moderate, or strong development).

- Approximate the geologic age for the deposits using Table C-2.

Note: Young alluvial fan deposits in general lack pavements because depositional processes are still active. Intermediate-age alluvial fan surfaces are generally smooth, well armored, and preserved. Old alluvial fan deposits generally lack pavements because the original fan surfaces have largely been removed by active erosional processes (Christenson and Purcell, 1985). Also, note that these indicators are found mainly on alluvial fans in desert environments.

What are the soil characteristics on the fan surfaces?

- Soil maps - use available soil maps to determine the stratigraphic characteristics of soil layers.

- Fieldwork - perform trenching to determining the stratigraphic characteristics of soil layer, if soil maps are not available. Examine for B horizon and carbonate development in the upper soil layer (2 to 3 feet of trenching).

Note: The typical stratigraphic layer of the first 12 inches, which is the zone of accumulation, is light brown or brownish for younger surfaces, and reddish brown or dark brown for older surfaces. Below this stratigraphic layer, carbonate deposition and development may become visible within the next ½- to 2-foot depth. Glossy crystals can be seen on rock and gravel for relatively younger surfaces, with some whitening if several hundred years old. For older surfaces, whitened (cemented) layer is formed. This layer is at least 6 inches thick and contains 15 percent or more calcium carbonate.

Step 3. Determine the characteristics of the drainage basin, areas at risk, and any development on the fan.

What and where are the sediment supply sources?

- Soil maps, aerial photos, and fieldwork - determine the sources of sediment production in the mountainous drainage basin, and estimate the volumes. Are the sediment supplies abundant, moderate, or limited just to sediment production from scours and erosions of the steep basin slopes and along the incised channels of the fan?
- Local flood control agency - obtain readily available data from local agency pertaining to the study area.

What are the basin shape and drainage patterns?

- Topographic maps and aerial photos - is the basin rounded or elongated? "The drainage basin of very active alluvial fans typically is bowl shaped where first and second order streams drain quickly to the hydrographic apex. Active fans are also associated with high relief drainage basins" (Hjalmarson, 1998).

- Topographic maps and aerial photos - determine whether the drainage patterns are tributary, distributary, and/or braided channels.

- Topographic maps and aerial photos - determine whether the first and second order channel segments are uniform or non-uniform, and assess the flow conveying capability of the drainage system.

What is the relative size of the drainage basin compared to the alluvial fan?

- Topographic maps, aerial photos, and field inspection - determine the area of the drainage basin. An alluvial fan is not very active if the drainage basin is relatively small compared to the size of the fan. (The range of drainage basin-to-fan size ratios has not been established through extensive study or research).

- Hydrology analysis or drainage design manual - determine the flood frequency relations and determine the 100-year runoff at the fan apex.

- Field work and surveying - determine the channel capacity at the topographic apex (basin mouth). Are the flows confined or unconfined to their channels? Use a simple normal depth computation for initial rating for each channel.

- Traditional hydraulic methods - determine the 100-year flood profile for any stable channels below the fan apex.

Where are the potential hazard areas on fan?

- Aerial photos, soil and geologic maps, vegetation, and flood reports - determine stable and unstable areas. Where has historic flooding occurred? Where have erosion and deposition occurred?

- Field work and surveying - determine the dimension, pattern, profile, and composition of channels such as width-to-depth ratio, gradient, and deposition. Also, examine the morphology, fragment assemblages, and other evidence of sedimentary processes on the fan surface.

- Geomorphic mapping, soil maps, aerial photos, and fieldwork - estimate areas of debris flow hazard, areas of erosion hazard, and areas of sedimentation hazard.

Where are the areas of current development?

- Site visit - determine the development density, residential as well as commercial buildings in areas at risk.

- Local government officials and developers - find out if significant development is anticipated within the vicinity and the type of mitigation measures to reduce potential structural damages.

- Local flood control agency - find out if structural control measures have been built or proposed for mitigating the potential risk.

The three-step procedure can be used to determine whether the landform is alluvial or non-alluvial, active or inactive, and to estimate or map the flood plains and the need for planning, management, and regulation.